US009369843B2

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Rudow et al.

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(54) **EXTRACTING PSEUDORANGE INFORMATION USING A CELLULAR DEVICE**

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(73) Assignee: **Trimble Navigation Limited**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 160 days.

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(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**

H04W 24/00 (2009.01)
H04M 11/00 (2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04W 4/023*** (2013.01); ***G01S 5/00*** (2013.01); ***G01S 19/25*** (2013.01); ***G01S 19/41*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC H04W 64/00; H04W 4/02

USPC 455/405, 456.1–456.6, 457; 342/357.22, 357.24, 357.44

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,225,842 A 7/1993 Brown et al.
5,345,244 A 9/1994 Gildea et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0508405 10/1992
EP 1729145 A1 12/2006

(Continued)

OTHER PUBLICATIONS

"PCT/US2013/078125 International Search Report and Written Opinion", Apr. 23, 2014, 25 pages.

(Continued)

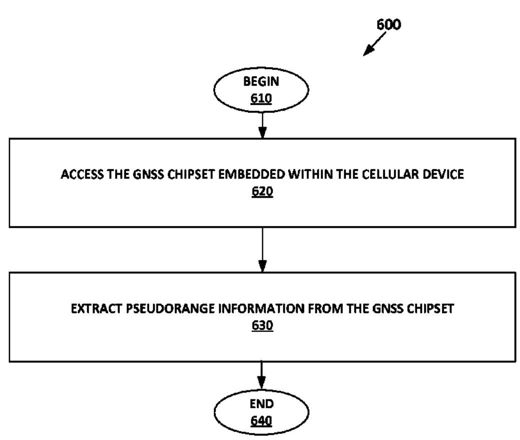
Primary Examiner — Dung Hong

(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend & Stockton LLP

(57) **ABSTRACT**

Pseudorange information is extracted by a cellular device from a Global Navigation Satellite System (GNSS) chipset of the cellular device. The cellular device accesses the GNSS chipset embedded within the cellular device where the GNSS chipset calculates pseudorange information for use by the GNSS chipset. The cellular device extracts the pseudorange information from the GNSS chipset for use elsewhere in the cellular device outside of the GNSS chipset.

53 Claims, 20 Drawing Sheets



(51) **Int. Cl.**

G01S 19/39	(2010.01)
G01S 19/41	(2010.01)
G01S 19/07	(2010.01)
H04W 4/02	(2009.01)
G01S 19/43	(2010.01)
G01S 19/48	(2010.01)
G01S 19/25	(2010.01)
G01S 5/00	(2006.01)
H04M 3/00	(2006.01)
H04W 64/00	(2009.01)

(52) **U.S. Cl.**
CPC ***G01S 19/43*** (2013.01); ***G01S 19/48*** (2013.01); ***H04M 3/00*** (2013.01); ***H04W 64/00*** (2013.01); *H04M 2250/10* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,379,224	A	1/1995	Brown et al.	
5,471,217	A	11/1995	Hatch et al.	
5,477,228	A	12/1995	Tiwari et al.	
5,523,761	A	6/1996	Gildea	
5,594,454	A	1/1997	Devereux et al.	
5,621,416	A	4/1997	Lennen	
5,740,048	A *	4/1998	Abel	G01C 21/165 701/470
5,805,108	A	9/1998	Lennen	
5,862,501	A	1/1999	Talbot et al.	
5,899,957	A	5/1999	Loomis	
5,903,235	A	5/1999	Nichols	
5,913,170	A	6/1999	Wortham	
6,067,046	A	5/2000	Nichols	
6,072,431	A	6/2000	Froeberg	
6,249,245	B1 *	6/2001	Watters	G01S 5/0027 342/357.4
6,324,473	B1	11/2001	Eschenbach	
6,408,178	B1 *	6/2002	Wickstrom	G01S 19/46 342/352
6,429,808	B1 *	8/2002	King	G01S 19/05 342/357.44
6,430,503	B1	8/2002	McBurney et al.	
6,473,030	B1	10/2002	McBurney et al.	
6,507,738	B1	1/2003	Allison et al.	
6,510,387	B2	1/2003	Fuchs et al.	
6,565,144	B1	5/2003	Crean et al.	
6,590,525	B2	7/2003	Yule et al.	
6,853,909	B2	2/2005	Scherzinger et al.	
7,003,112	B1	2/2006	Froeberg	
7,043,364	B2	5/2006	Scherzinger	
7,151,489	B2	12/2006	Pande et al.	
7,191,097	B1	3/2007	Lee et al.	
7,480,511	B2	1/2009	O'Meagher	
7,541,974	B2	6/2009	Scherzinger et al.	
7,570,204	B1 *	8/2009	McGraw	G01S 19/44 342/357.27
7,908,106	B2	3/2011	Cho et al.	
7,961,141	B2	6/2011	Dai et al.	
8,024,144	B2	9/2011	Kludas et al.	
8,032,152	B2	10/2011	Manson et al.	
8,044,852	B2	10/2011	Green et al.	
8,068,848	B2	11/2011	Manson et al.	
8,068,849	B2	11/2011	Manson et al.	
8,078,192	B2	12/2011	Wirola et al.	
8,081,987	B2	12/2011	Manson et al.	
8,081,988	B2	12/2011	Manson et al.	
8,081,989	B2	12/2011	Manson et al.	
8,085,196	B2	12/2011	Whitehead	
8,085,387	B2	12/2011	Kludas et al.	
8,095,149	B2	1/2012	Manson et al.	
8,134,497	B2	3/2012	Janky et al.	
8,136,545	B2	3/2012	Jablonski	
8,242,956	B2	8/2012	Lamance et al.	
8,339,311	B2	12/2012	Walley et al.	
8,368,875	B2	2/2013	Kludas et al.	
8,447,519	B2	5/2013	Basnayake et al.	
8,699,409	B2	4/2014	Aryan et al.	
8,719,188	B2	5/2014	Kuhn et al.	
9,037,527	B2	5/2015	Kuhn et al.	
2001/0017599	A1	8/2001	Yule et al.	
2002/0072854	A1	6/2002	Fuchs et al.	
2002/0186180	A1	12/2002	Duda	
2003/0114984	A1	6/2003	Scherzinger et al.	
2005/0064878	A1	3/2005	O'Meagher et al.	
2005/0104774	A1	5/2005	Pande et al.	
2006/0146136	A1	7/2006	Cho et al.	
2007/0139262	A1	6/2007	Scherzinger et al.	
2008/0263097	A1	10/2008	Manson et al.	
2008/0319664	A1	12/2008	Kremin et al.	
2009/0024325	A1	1/2009	Scherzinger et al.	
2009/0083430	A1	3/2009	Edge et al.	
2009/0093959	A1	4/2009	Scherzinger et al.	
2009/0189804	A1 *	7/2009	Ashjaee	G01S 19/14 342/357.27
2009/0262016	A1 *	10/2009	Wirola	G01S 19/04 342/357.27
2010/0057359	A1	3/2010	Caballero et al.	
2010/0079333	A1 *	4/2010	Janky	G01S 19/43 342/357.24
2010/0141510	A1 *	6/2010	Dai	G01S 19/43 342/357.31
2010/0231443	A1	9/2010	Whitehead	
2010/0260150	A1	10/2010	Aryan et al.	
2011/0018761	A1 *	1/2011	Walley	G01S 19/35 342/357.28
2011/0064312	A1	3/2011	Janky et al.	
2011/0163914	A1	7/2011	Seymour et al.	
2011/0187590	A1	8/2011	Leandro	
2011/0195687	A1	8/2011	Das et al.	
2011/0267230	A1	11/2011	Lamance et al.	
2011/0285587	A1 *	11/2011	Vollath	G01S 19/07 342/357.62
2012/0116676	A1	5/2012	Basnayake et al.	
2012/0163656	A1	6/2012	Wang et al.	
2012/0166137	A1	6/2012	Grässer et al.	
2012/0330601	A1	12/2012	Soubra et al.	
2013/0027246	A1 *	1/2013	Hadef	G01S 19/40 342/357.25
2013/0243250	A1	9/2013	France et al.	
2014/0081571	A1	3/2014	Briggs et al.	
2014/0184442	A1	7/2014	Large et al.	
2014/0187193	A1	7/2014	Rudow et al.	
2014/0240170	A1	8/2014	Rudow et al.	
2014/0253375	A1	9/2014	Rudow et al.	
2014/0292569	A1	10/2014	Wallace et al.	
2014/0292570	A1	10/2014	Wallace et al.	
2014/0375493	A1	12/2014	Weisenburger et al.	
2014/0378170	A1	12/2014	Rudow et al.	
2014/0378171	A1	12/2014	Rudow et al.	
2015/0009067	A1	1/2015	Rudow et al.	
2015/0043012	A1	2/2015	Rudow et al.	
2015/0045058	A1	2/2015	Rudow et al.	
2015/0045059	A1	2/2015	Rudow et al.	
2015/0050907	A1	2/2015	Rudow et al.	
2015/0057028	A1	2/2015	Rudow et al.	

FOREIGN PATENT DOCUMENTS

EP	2275778	A1	1/2011
EP	2722647	A1	4/2014
KR	20110085744		7/2011
KR	101241171	B1	3/2013
WO	2005/045458		5/2005
WO	2008089792	A1	7/2008
WO	2009074654	A1	6/2009
WO	2011120141	A1	10/2011

OTHER PUBLICATIONS

Rho, "Dual-Frequency GPS Precise Point Positioning with WADGPS Corrections", Department of Geodesy and Geomatics Engineering, University of new Brunswick, Fredericton, N.B. Canada, Sep. 13-16, 2005, 1470-1482.

(56) **References Cited**

OTHER PUBLICATIONS

Afzal, "Design Methodology for Dual Frequency Configurable GPD Receiver", ION GNSS 2010, Session E5, Portland, OR, Sep. 21-24, 2010, 9 Pages.
Brown, "TIDGET Mayday System for Motorists", Presented at IEEE Position Location and Navigation Symposium (PLANS) '94 Las Vegas, NV, Apr. 1994, 7 pages.
"TRK Bridge-E", Intuicom, Inc. www.intuicom.com, 2 pages.
"Spirit Level with bubble", https://play.google.com/store/apps/details?id=com.zabaaanapps.android.level, Mar. 25, 2014.
"Technical Tips from Inland GPS", Trimble TSC2—RTK over internet—establishing IP Connection, Jun. 14, 2011, 8 pages.
"Theodolite", Hunter Research & Technology, Mar. 24, 2014, 1 Page.
"Trimble S8 Total Station Datasheet", Trimble Navigation Limited, 2013, 4 Pages.
"Wireless RTK Bridge—Cellular User Guide", Revision 1.4, 2009, 47 pages.
Ike, "Spike: Laser Accurate Measurement & Modeling on Smartphones", https://www.kickstarter.com/projects/ikegps/spike-laser-accurate-measurement-and-modelling-on?ref=nav_search, Oct. 2, 2013, 14 Pages.
Hatch, "The Synergism of GPS Code and Carrier Measurements", Proceedings of the Third International Geodetic Symposium on Satellite Doppler Positioning, 1982, 1213-1232.
Landau, et al., "Virtual Reference Stations Versus Broadcast Solutions in Network RTK", GNSS 2003, Graz, Austria, Apr. 2003, 15 pages.
Thipparthi, "Imporving Prositional Accuracy Using Carrier Smoothing Techniques in Inexpensive GPS Receivers", MSEE Thesis, New Menixo State University, Las Cruces, NM, Feb. 2004, 101 Pages.
"Comparison of Photogrammetry Software", http://en.wikipedia.org/wiki/Comparison_of_photogrammetry_software, Jul. 8, 2015, 4 pages.
"Photogrammetry", http://en.wikipedia.org/wiki/Photogrammetry, Jun. 25, 2015, 5 pages.
"Pi Pelican Imaging: Life in 3D", http://www.pelicanimaging.com, 2015, 3 pages.
Church, "Close Range Photogrammetry vs. 3D Scanning of Archeological Documentation", http://ncptt.nps.gov/blog/close-range-photogrammetry-vs-3d-scanning-for-archaeological-documentation/, Nov. 6, 2012, 10 pages.
Grussenmeyer, et al., "A comparison of photogrammetry software packages for the documentation of buildings", http://halshs.archives-ouvertes.fr/docs/00/28/12/54/PDF/grussenmeyer_alkhalil_FIG2000.PDF, May 21, 2008, 9 pages.
"PCT/US2015/035328 International Search Report", Oct. 15, 2015, pp. 1-13.
"PCT/US2015/035346 International Search Report", Oct. 13, 2015, pp. 1-12.
Afzal, "Design Methodology for a Dual Frequency Configurable GPS Receiver", Proceedings of the 23rd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2010), Sep. 24, 2010, pp. 2892-2900.
Guixens, et al., "System Aspects and Practical Results for Precise Car Navigation with Modern Civil Signals Using a Software Receiver", Proceedings of the 21st International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2008), Sep. 19, 2008, pp. 2280-2292.
Haak, "A Multi-Purpose Software GNSS Receiver for Automotive Applications", Proceedings of the 23rd International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2010), Sep. 24, 2010, pp. 1869-1874.
Ruegamer, et al., "A Flexible and Portable Multiband GNSS Front-end System", Proceedings of the 25th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS 2012), Sep. 21, 2012, pp. 2378-2389.
"PCT/US2015/052370 International Search Report", Jan. 8, 2016, pp. 1-13.

* cited by examiner

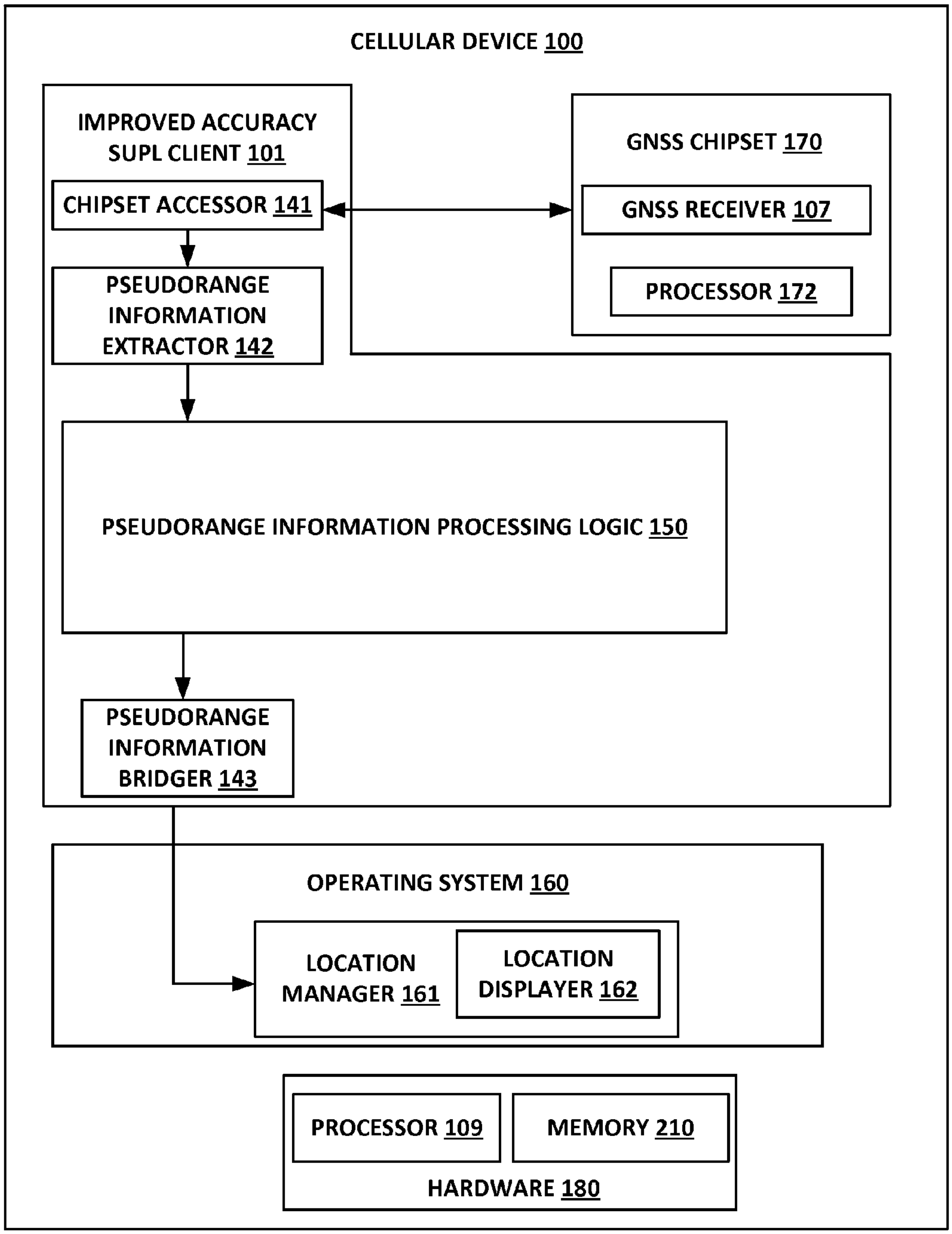

CELLULAR DEVICE 100
IMPROVED ACCURACY SUPL CLIENT 101
CHIPSET ACCESSOR 141
PSEUDORANGE INFORMATION EXTRACTOR 142
GNSS CHIPSET 170
GNSS RECEIVER 107
PROCESSOR 172
PSEUDORANGE INFORMATION PROCESSING LOGIC 150
PSEUDORANGE INFORMATION BRIDGER 143
OPERATING SYSTEM 160
LOCATION MANAGER 161
LOCATION DISPLAYER 162
PROCESSOR 109
MEMORY 210
HARDWARE 180

FIG. 1A

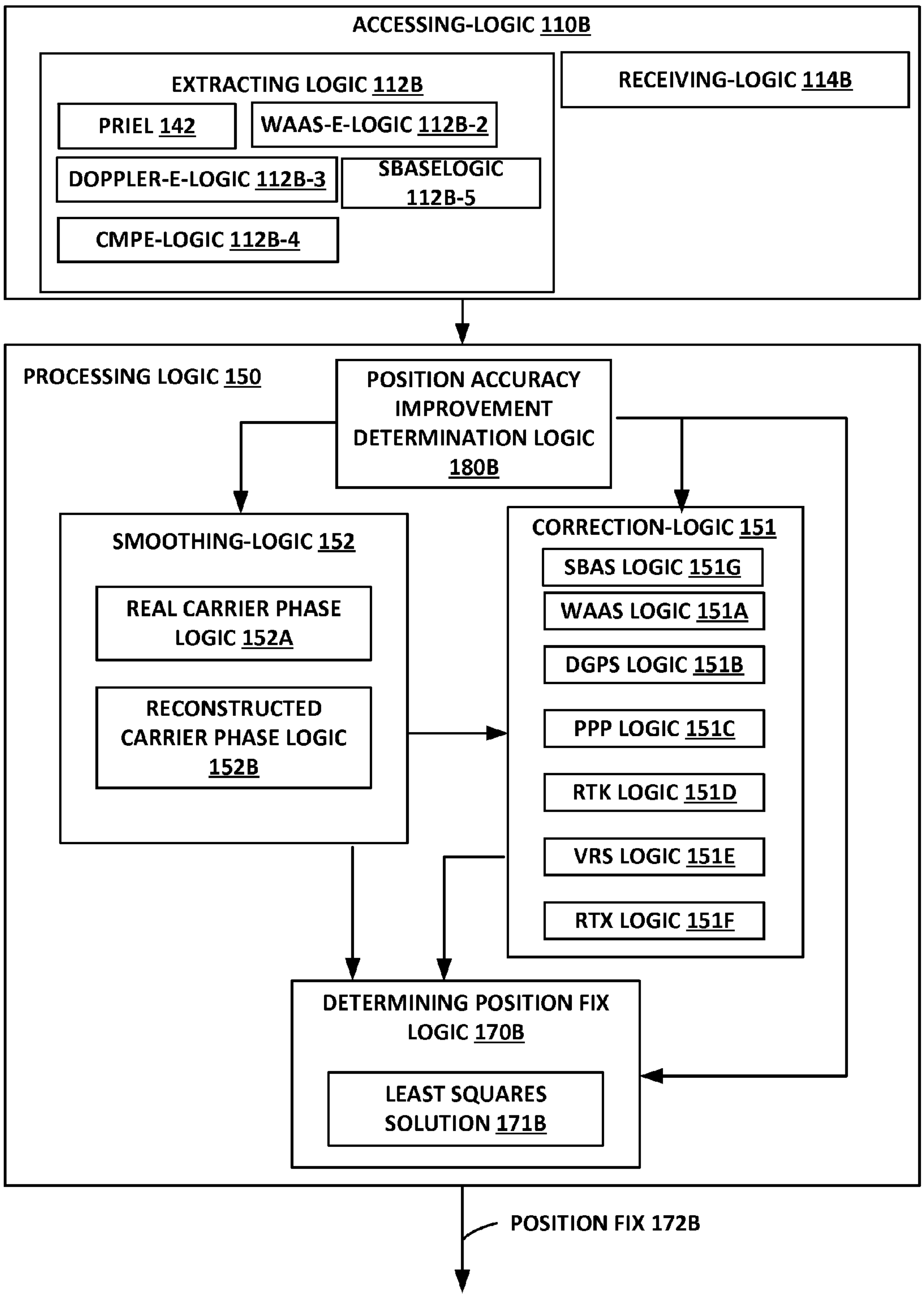

ACCESSING-LOGIC 110B
EXTRACTING LOGIC 112B
PRIEL 142
WAAS-E-LOGIC 112B-2
DOPPLER-E-LOGIC 112B-3
SBASELOGIC 112B-5
CMPE-LOGIC 112B-4
RECEIVING-LOGIC 114B
PROCESSING LOGIC 150
POSITION ACCURACY IMPROVEMENT DETERMINATION LOGIC 180B
SMOOTHING-LOGIC 152
REAL CARRIER PHASE LOGIC 152A
RECONSTRUCTED CARRIER PHASE LOGIC 152B
CORRECTION-LOGIC 151
SBAS LOGIC 151G
WAAS LOGIC 151A
DGPS LOGIC 151B
PPP LOGIC 151C
RTK LOGIC 151D
VRS LOGIC 151E
RTX LOGIC 151F
DETERMINING POSITION FIX LOGIC 170B
LEAST SQUARES SOLUTION 171B
POSITION FIX 172B

FIG. 1B

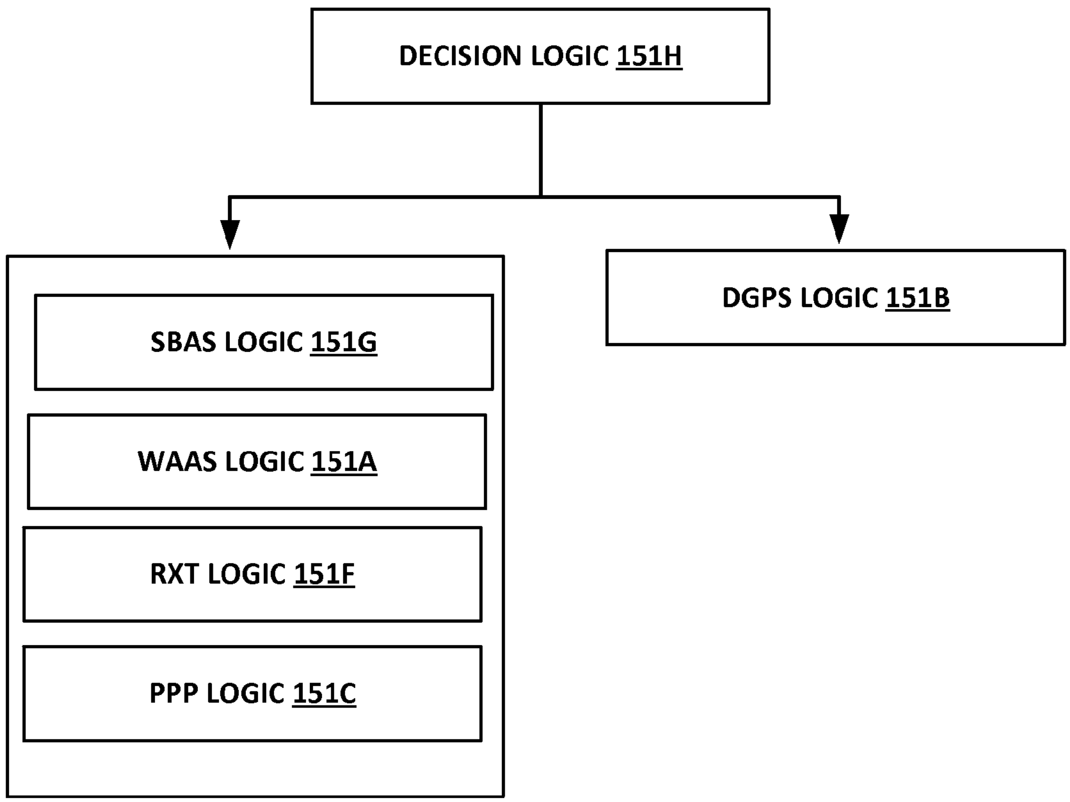

DECISION LOGIC 151H
SBAS LOGIC 151G
WAAS LOGIC 151A
RXT LOGIC 151F
PPP LOGIC 151C
DGPS LOGIC 151B

FIG. 1C

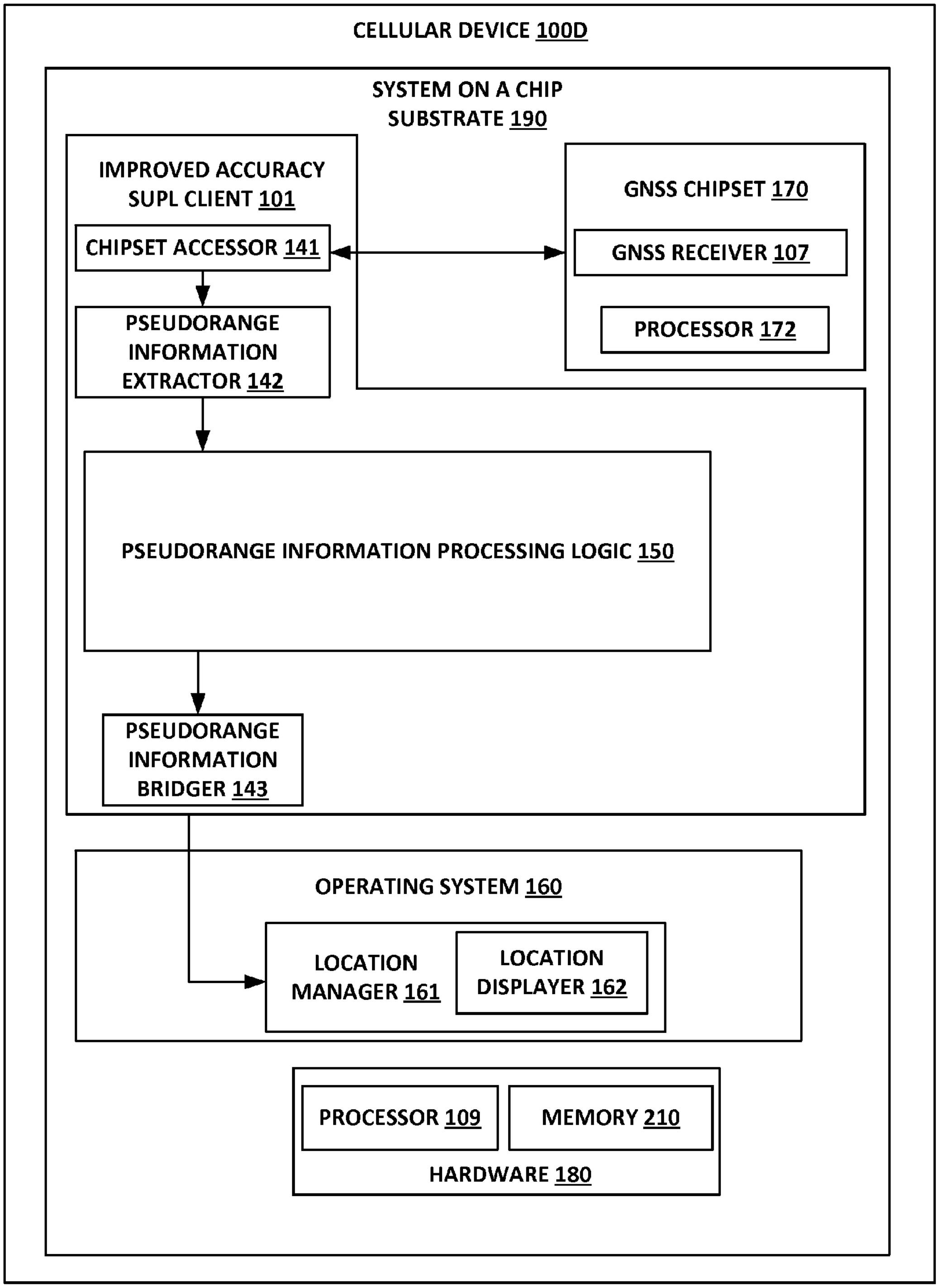

CELLULAR DEVICE 100D
SYSTEM ON A CHIP SUBSTRATE 190
IMPROVED ACCURACY SUPL CLIENT 101
CHIPSET ACCESSOR 141
PSEUDORANGE INFORMATION EXTRACTOR 142
GNSS CHIPSET 170
GNSS RECEIVER 107
PROCESSOR 172
PSEUDORANGE INFORMATION PROCESSING LOGIC 150
PSEUDORANGE INFORMATION BRIDGER 143
OPERATING SYSTEM 160
LOCATION MANAGER 161
LOCATION DISPLAYER 162
PROCESSOR 109
MEMORY 210
HARDWARE 180

FIG. 1D

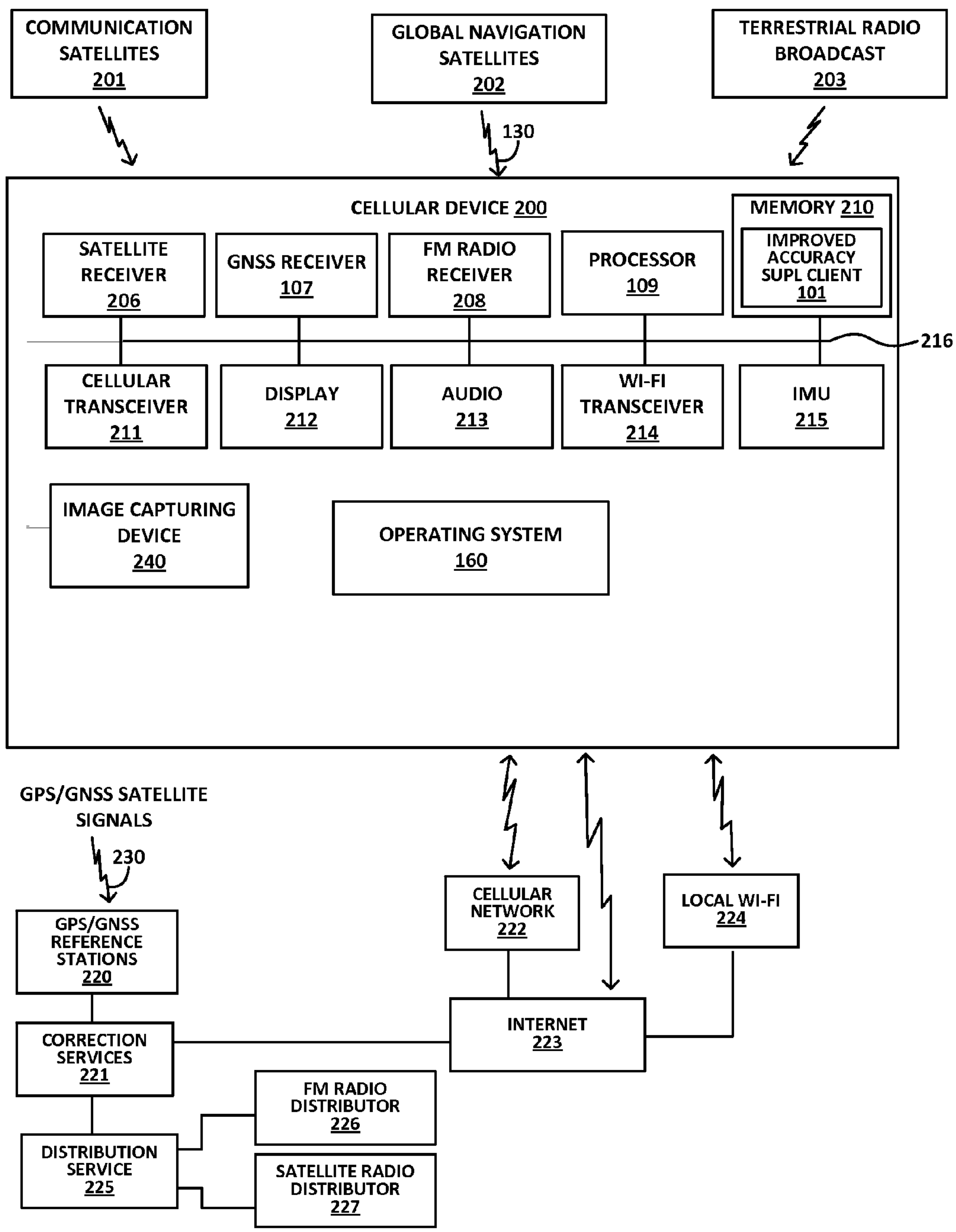
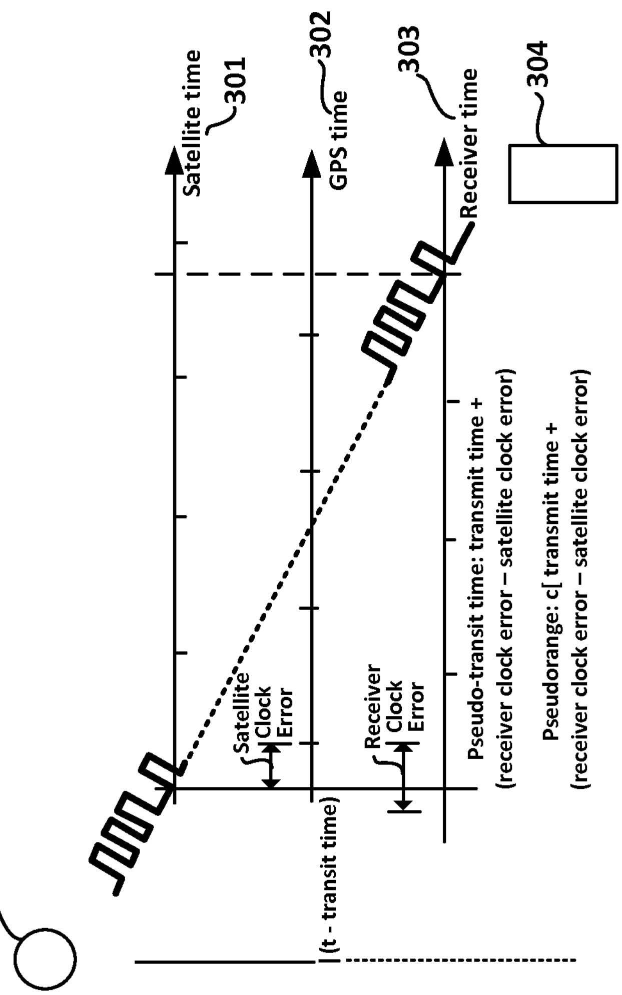

COMMUNICATION SATELLITES 201
GLOBAL NAVIGATION SATELLITES 202
TERRESTRIAL RADIO BROADCAST 203
130
CELLULAR DEVICE 200
MEMORY 210
IMPROVED ACCURACY SUPL CLIENT 101
SATELLITE RECEIVER 206
GNSS RECEIVER 107
FM RADIO RECEIVER 208
PROCESSOR 109
216
CELLULAR TRANSCEIVER 211
DISPLAY 212
AUDIO 213
WI-FI TRANSCEIVER 214
IMU 215
IMAGE CAPTURING DEVICE 240
OPERATING SYSTEM 160
GPS/GNSS SATELLITE SIGNALS
230
GPS/GNSS REFERENCE STATIONS 220
CELLULAR NETWORK 222
LOCAL WI-FI 224
CORRECTION SERVICES 221
INTERNET 223
FM RADIO DISTRIBUTOR 226
DISTRIBUTION SERVICE 225
SATELLITE RADIO DISTRIBUTOR 227

FIG. 2



Satellite time
301
GPS time
302
Receiver time
303
304
305
Satellite Clock Error
Receiver Clock Error
(t - transit time)
Pseudo-transit time: transmit time + (receiver clock error – satellite clock error)
Pseudorange: c[transmit time + (receiver clock error – satellite clock error)

FIG. 3

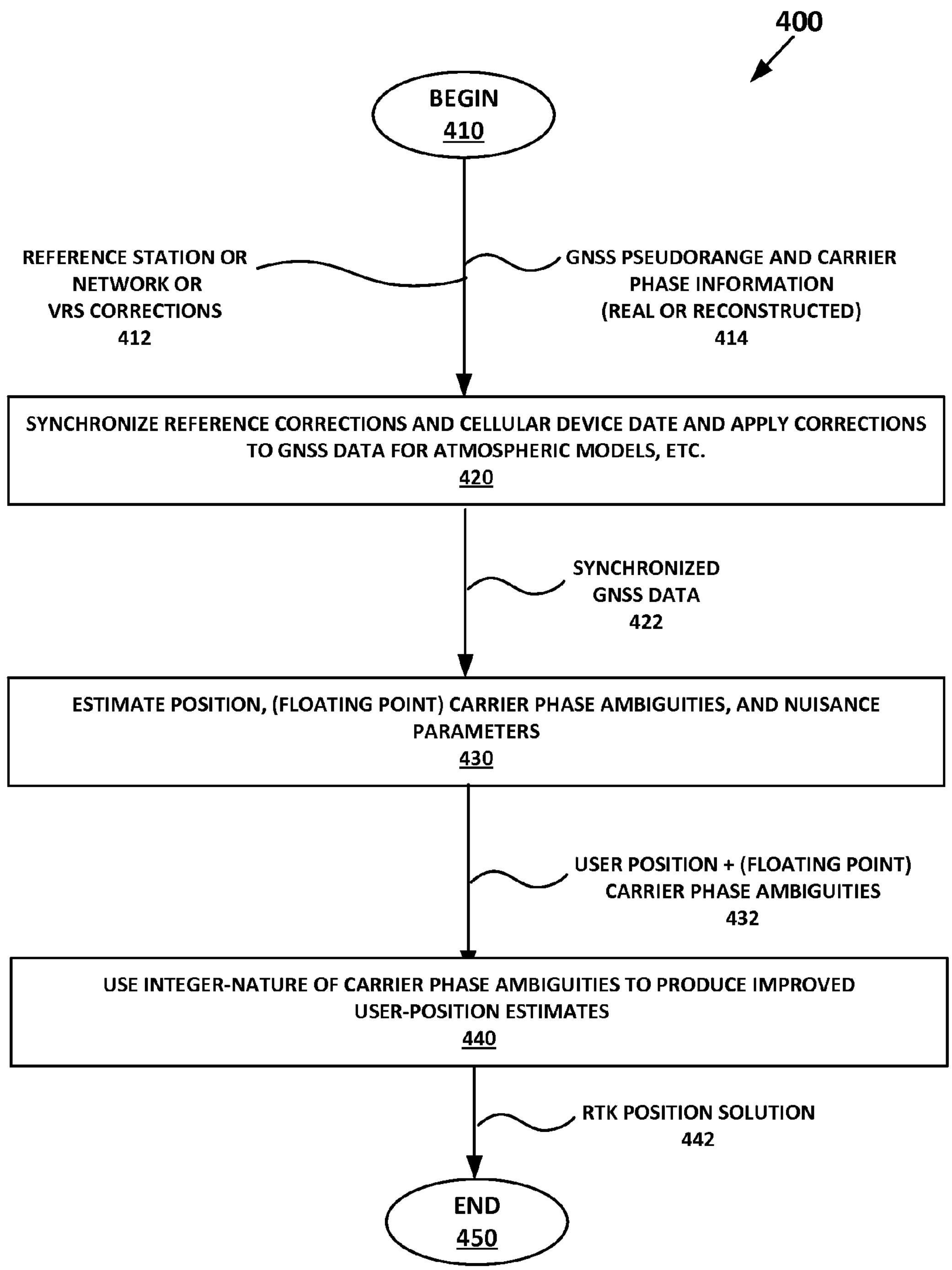

400
BEGIN
410
REFERENCE STATION OR
NETWORK OR
VRS CORRECTIONS
412
GNSS PSEUDORANGE AND CARRIER
PHASE INFORMATION
(REAL OR RECONSTRUCTED)
414
SYNCHRONIZE REFERENCE CORRECTIONS AND CELLULAR DEVICE DATE AND APPLY CORRECTIONS
TO GNSS DATA FOR ATMOSPHERIC MODELS, ETC.
420
SYNCHRONIZED
GNSS DATA
422
ESTIMATE POSITION, (FLOATING POINT) CARRIER PHASE AMBIGUITIES, AND NUISANCE
PARAMETERS
430
USER POSITION + (FLOATING POINT)
CARRIER PHASE AMBIGUITIES
432
USE INTEGER-NATURE OF CARRIER PHASE AMBIGUITIES TO PRODUCE IMPROVED
USER-POSITION ESTIMATES
440
RTK POSITION SOLUTION
442
END
450

FIG. 4

500A

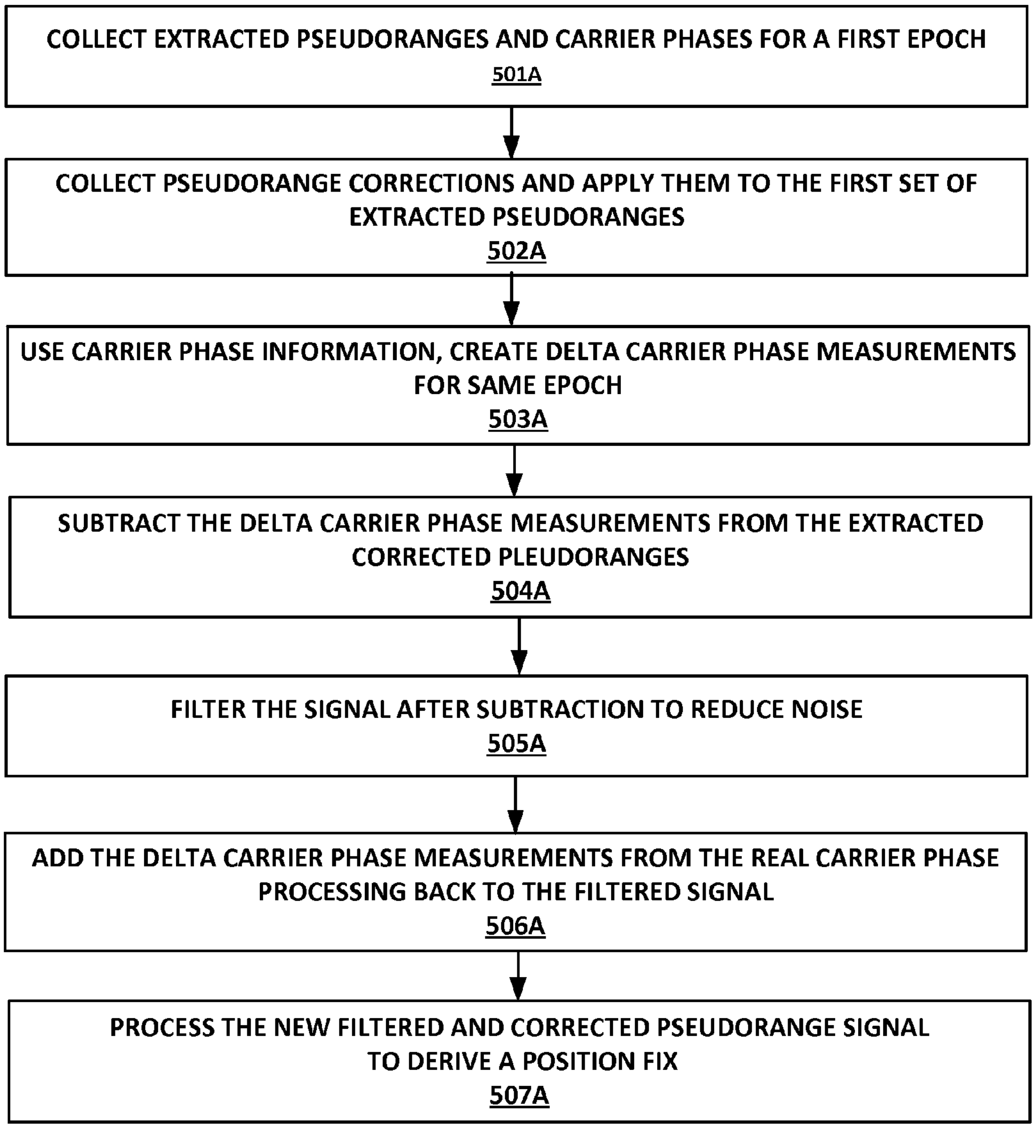

COLLECT EXTRACTED PSEUDORANGES AND CARRIER PHASES FOR A FIRST EPOCH
501A
COLLECT PSEUDORANGE CORRECTIONS AND APPLY THEM TO THE FIRST SET OF EXTRACTED PSEUDORANGES
502A
USE CARRIER PHASE INFORMATION, CREATE DELTA CARRIER PHASE MEASUREMENTS FOR SAME EPOCH
503A
SUBTRACT THE DELTA CARRIER PHASE MEASUREMENTS FROM THE EXTRACTED CORRECTED PLEUDORANGES
504A
FILTER THE SIGNAL AFTER SUBTRACTION TO REDUCE NOISE
505A
ADD THE DELTA CARRIER PHASE MEASUREMENTS FROM THE REAL CARRIER PHASE PROCESSING BACK TO THE FILTERED SIGNAL
506A
PROCESS THE NEW FILTERED AND CORRECTED PSEUDORANGE SIGNAL TO DERIVE A POSITION FIX
507A

FIG. 5A

500B

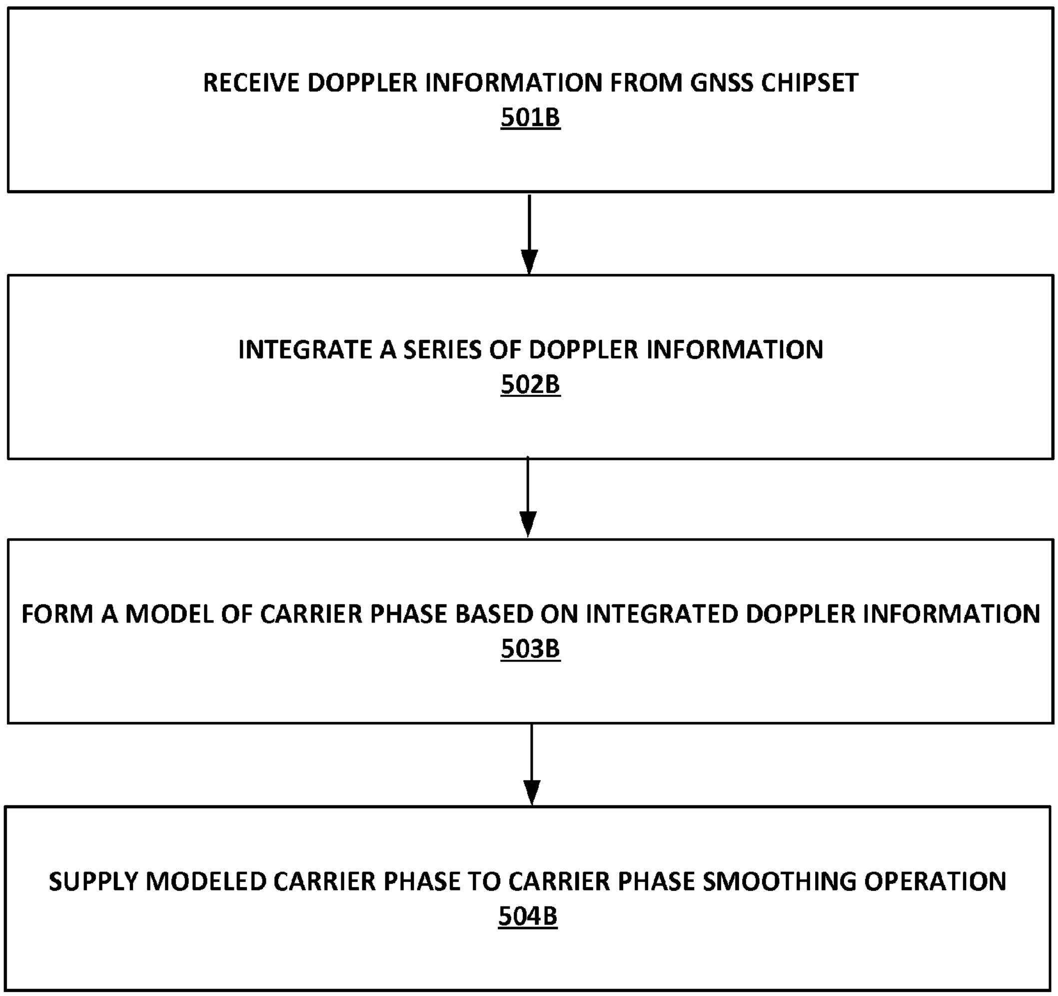

RECEIVE DOPPLER INFORMATION FROM GNSS CHIPSET
501B
INTEGRATE A SERIES OF DOPPLER INFORMATION
502B
FORM A MODEL OF CARRIER PHASE BASED ON INTEGRATED DOPPLER INFORMATION
503B
SUPPLY MODELED CARRIER PHASE TO CARRIER PHASE SMOOTHING OPERATION
504B

FIG. 5B

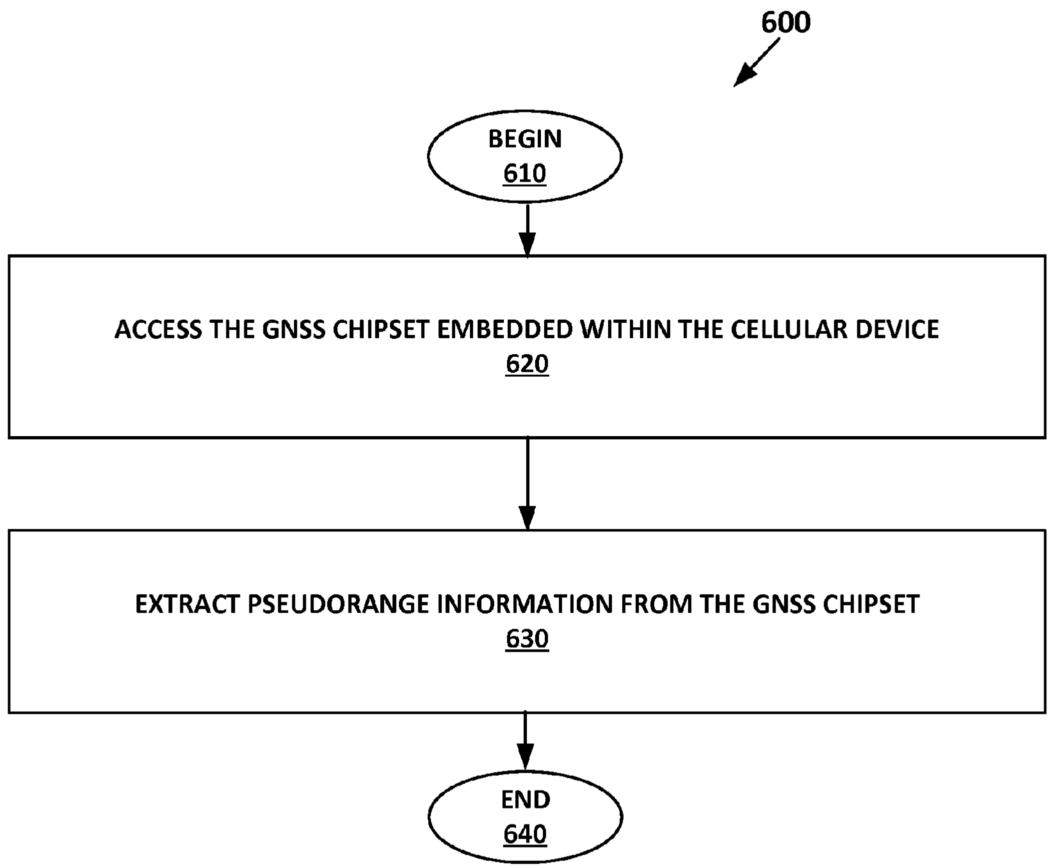

600
BEGIN
610
ACCESS THE GNSS CHIPSET EMBEDDED WITHIN THE CELLULAR DEVICE
620
EXTRACT PSEUDORANGE INFORMATION FROM THE GNSS CHIPSET
630
END
640

FIG. 6

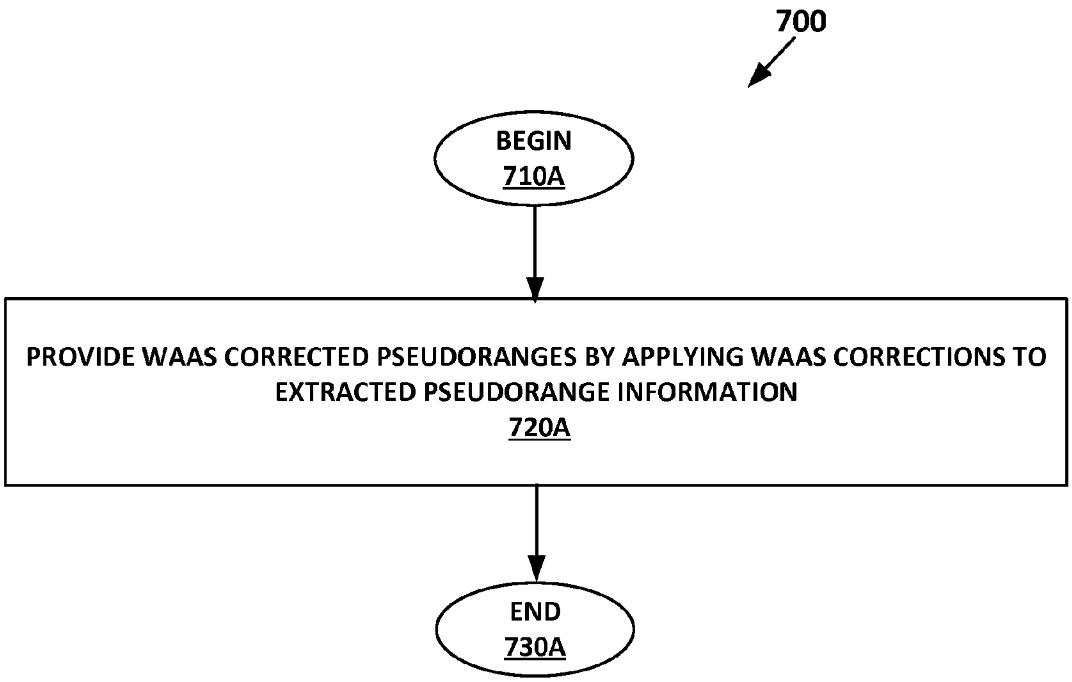

700
BEGIN
710A
PROVIDE WAAS CORRECTED PSEUDORANGES BY APPLYING WAAS CORRECTIONS TO EXTRACTED PSEUDORANGE INFORMATION
720A
END
730A

FIG. 7A

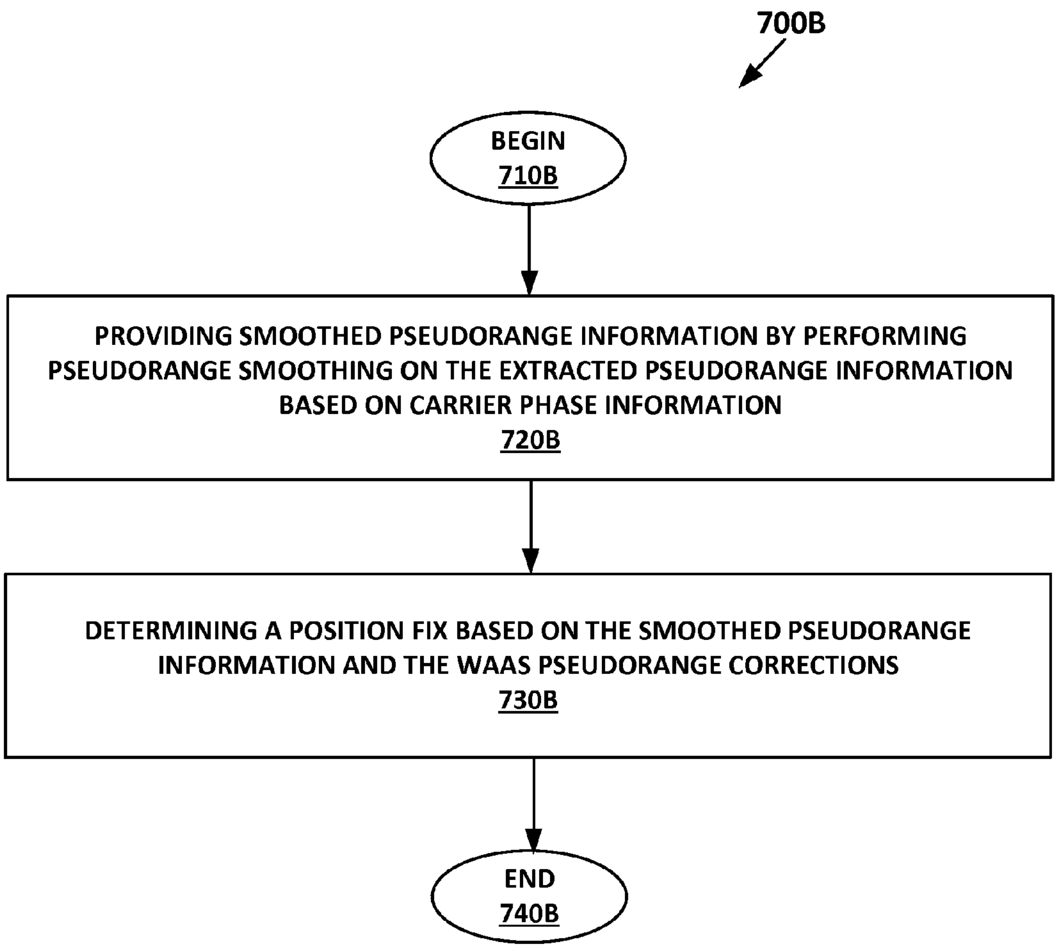

700B
BEGIN
710B
PROVIDING SMOOTHED PSEUDORANGE INFORMATION BY PERFORMING PSEUDORANGE SMOOTHING ON THE EXTRACTED PSEUDORANGE INFORMATION BASED ON CARRIER PHASE INFORMATION
720B
DETERMINING A POSITION FIX BASED ON THE SMOOTHED PSEUDORANGE INFORMATION AND THE WAAS PSEUDORANGE CORRECTIONS
730B
END
740B

FIG. 7B

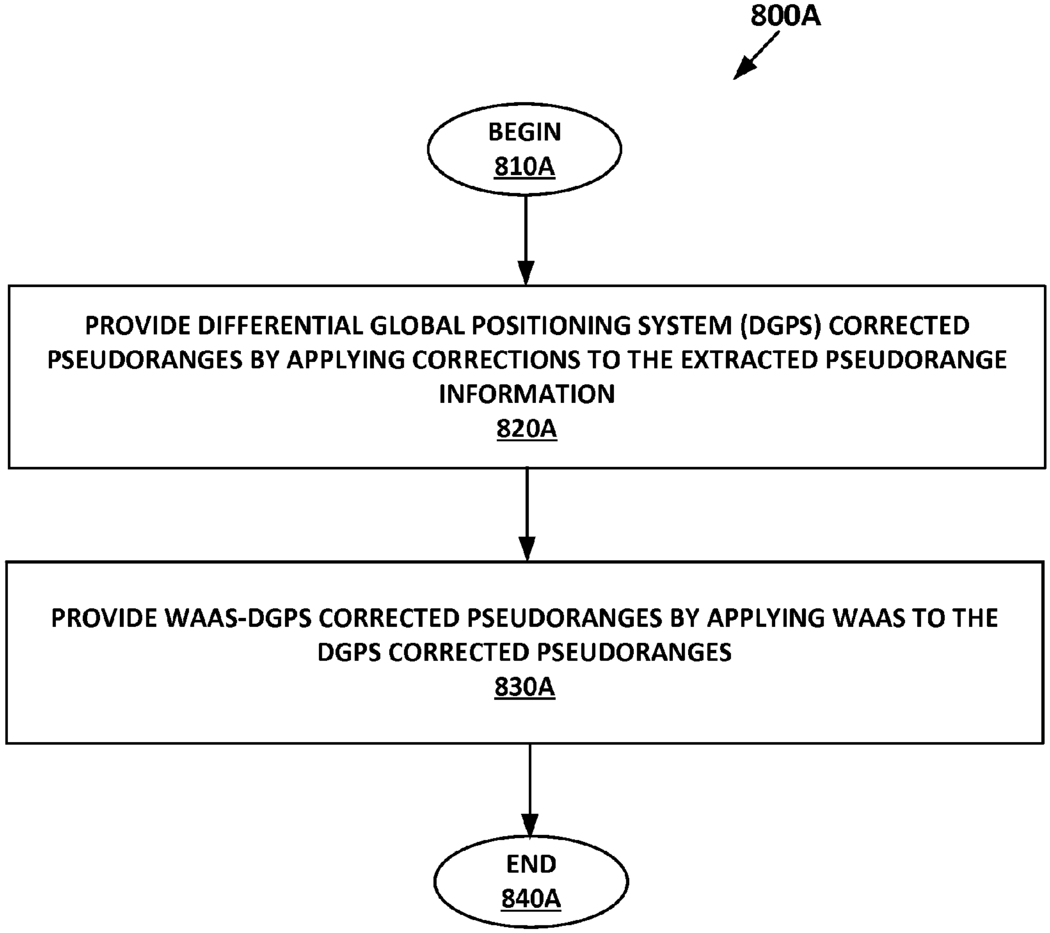

800A
BEGIN
810A
PROVIDE DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) CORRECTED PSEUDORANGES BY APPLYING CORRECTIONS TO THE EXTRACTED PSEUDORANGE INFORMATION
820A
PROVIDE WAAS-DGPS CORRECTED PSEUDORANGES BY APPLYING WAAS TO THE DGPS CORRECTED PSEUDORANGES
830A
END
840A

FIG. 8A

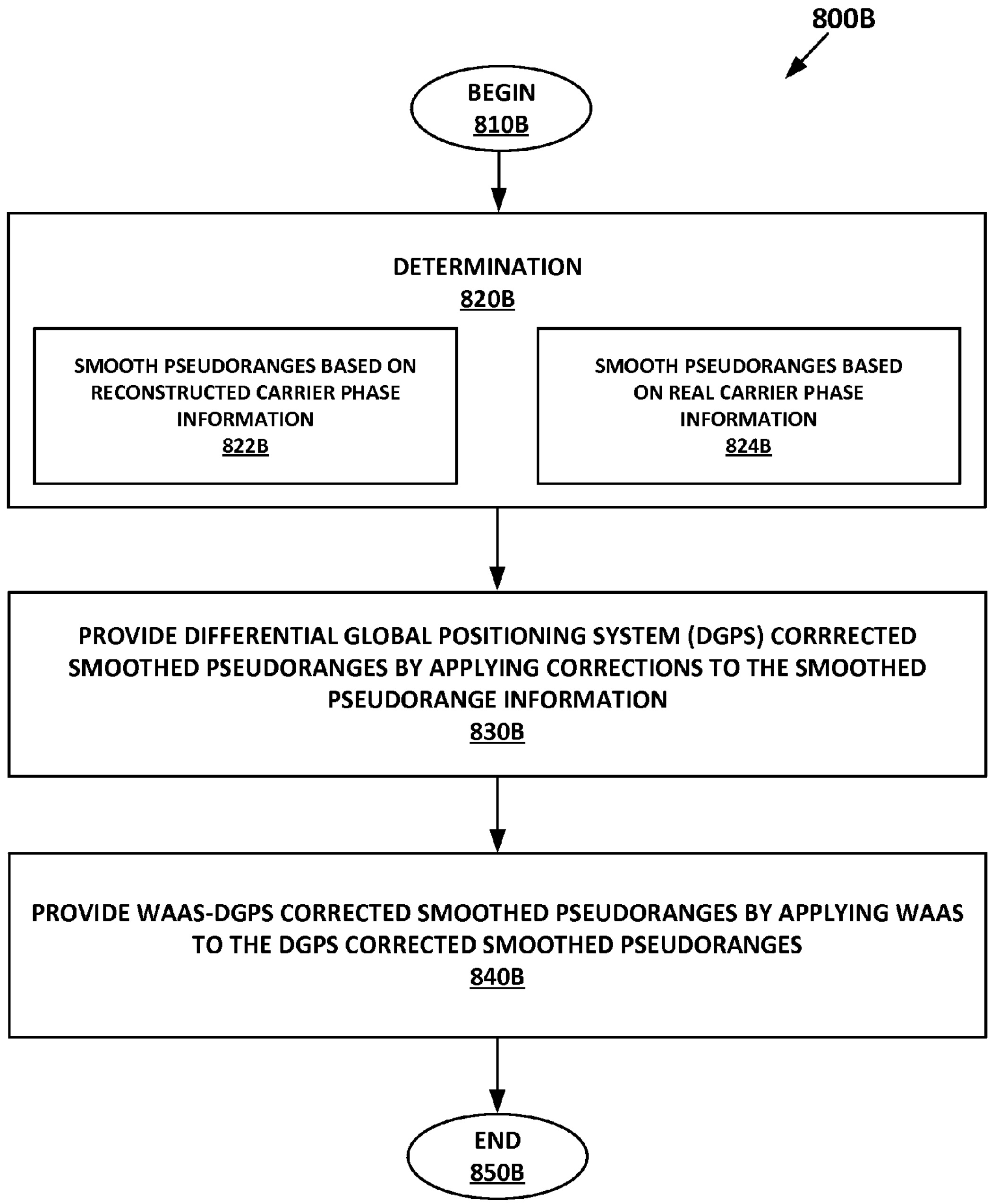

800B
BEGIN
810B
DETERMINATION
820B
SMOOTH PSEUDORANGES BASED ON RECONSTRUCTED CARRIER PHASE INFORMATION
822B
SMOOTH PSEUDORANGES BASED ON REAL CARRIER PHASE INFORMATION
824B
PROVIDE DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) CORRRECTED SMOOTHED PSEUDORANGES BY APPLYING CORRECTIONS TO THE SMOOTHED PSEUDORANGE INFORMATION
830B
PROVIDE WAAS-DGPS CORRECTED SMOOTHED PSEUDORANGES BY APPLYING WAAS TO THE DGPS CORRECTED SMOOTHED PSEUDORANGES
840B
END
850B

FIG. 8B

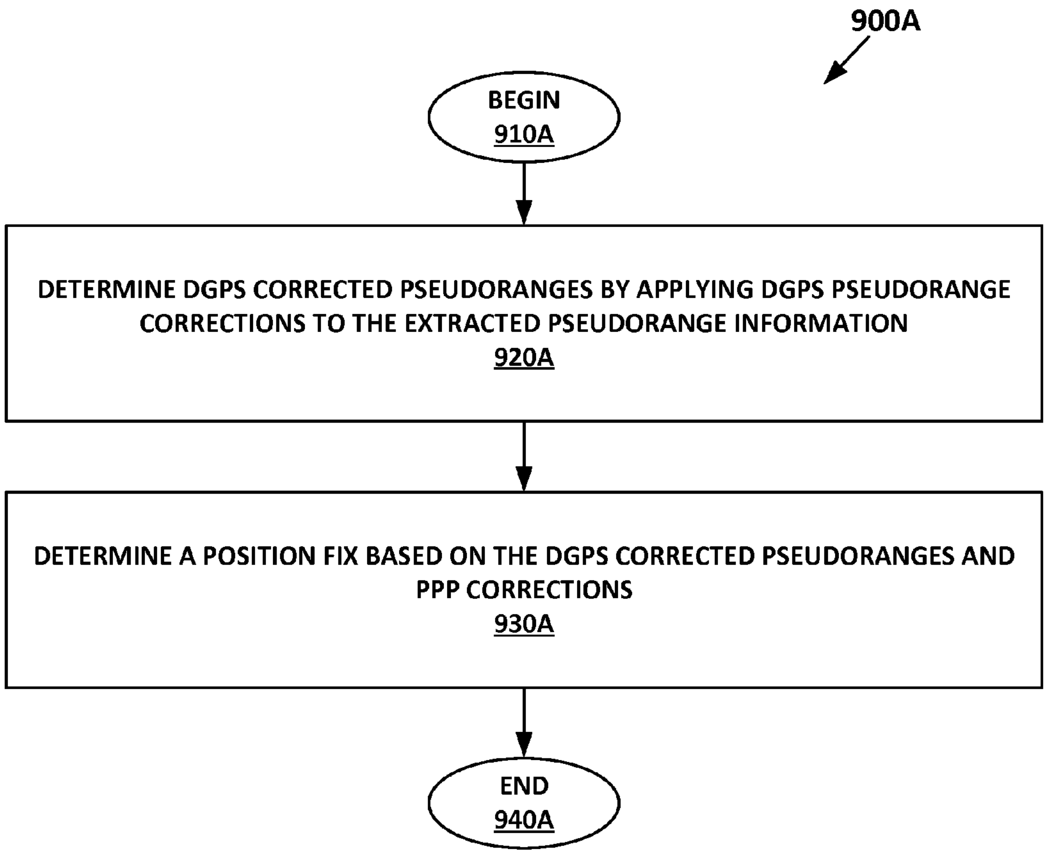

900A
BEGIN
910A
DETERMINE DGPS CORRECTED PSEUDORANGES BY APPLYING DGPS PSEUDORANGE CORRECTIONS TO THE EXTRACTED PSEUDORANGE INFORMATION
920A
DETERMINE A POSITION FIX BASED ON THE DGPS CORRECTED PSEUDORANGES AND PPP CORRECTIONS
930A
END
940A

FIG. 9A

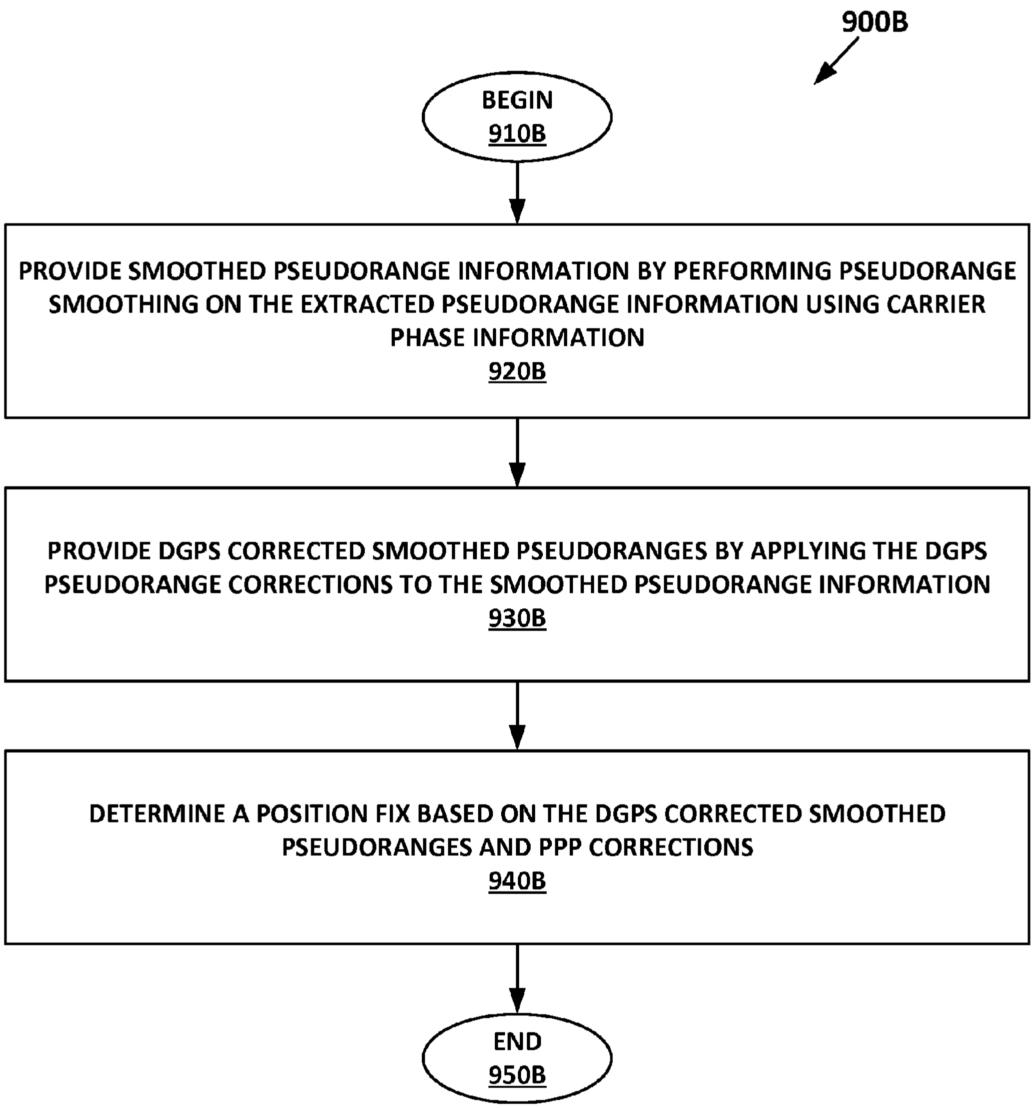

900B
BEGIN
910B
PROVIDE SMOOTHED PSEUDORANGE INFORMATION BY PERFORMING PSEUDORANGE SMOOTHING ON THE EXTRACTED PSEUDORANGE INFORMATION USING CARRIER PHASE INFORMATION
920B
PROVIDE DGPS CORRECTED SMOOTHED PSEUDORANGES BY APPLYING THE DGPS PSEUDORANGE CORRECTIONS TO THE SMOOTHED PSEUDORANGE INFORMATION
930B
DETERMINE A POSITION FIX BASED ON THE DGPS CORRECTED SMOOTHED PSEUDORANGES AND PPP CORRECTIONS
940B
END
950B

FIG. 9B

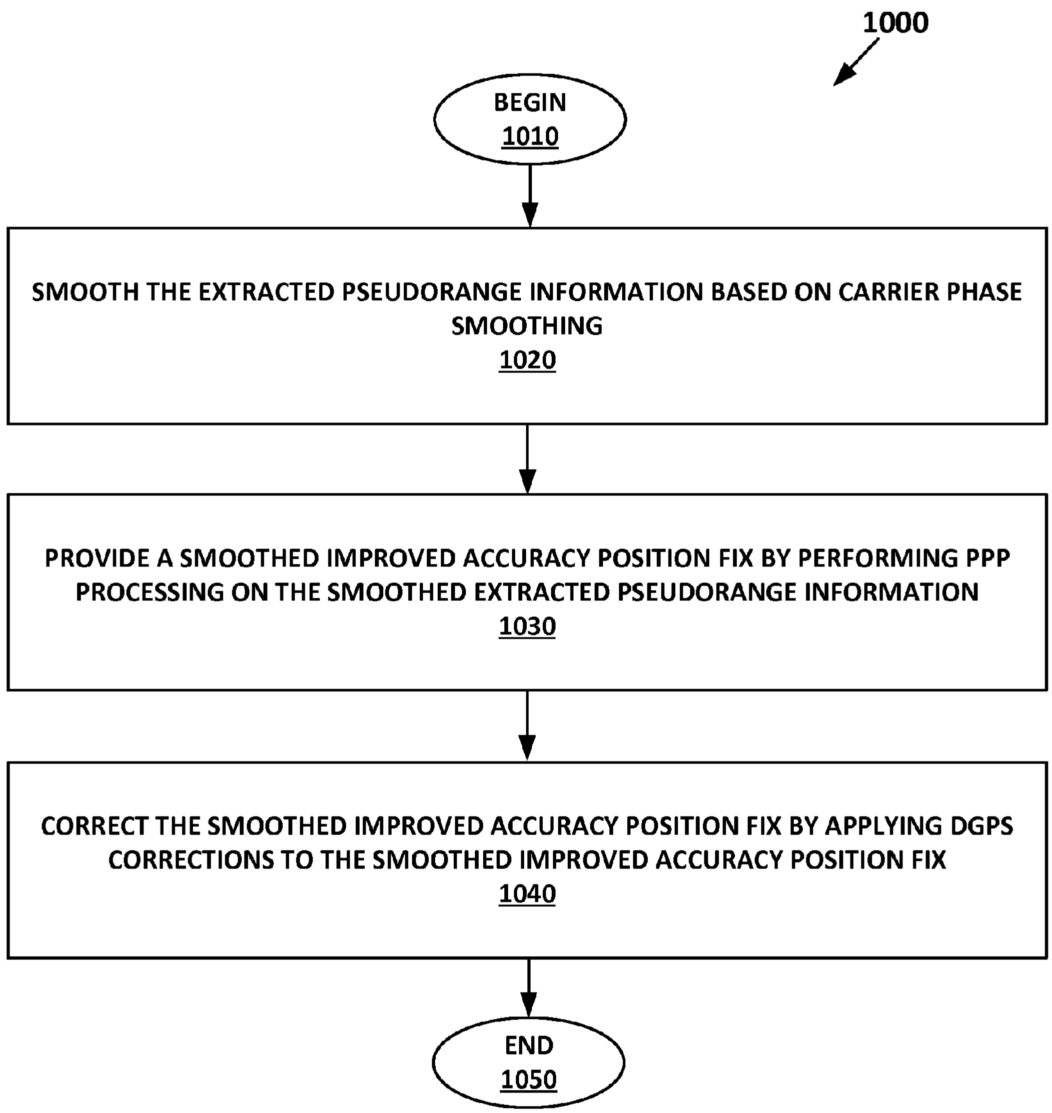

1000
BEGIN
1010
SMOOTH THE EXTRACTED PSEUDORANGE INFORMATION BASED ON CARRIER PHASE SMOOTHING
1020
PROVIDE A SMOOTHED IMPROVED ACCURACY POSITION FIX BY PERFORMING PPP PROCESSING ON THE SMOOTHED EXTRACTED PSEUDORANGE INFORMATION
1030
CORRECT THE SMOOTHED IMPROVED ACCURACY POSITION FIX BY APPLYING DGPS CORRECTIONS TO THE SMOOTHED IMPROVED ACCURACY POSITION FIX
1040
END
1050

FIG. 10

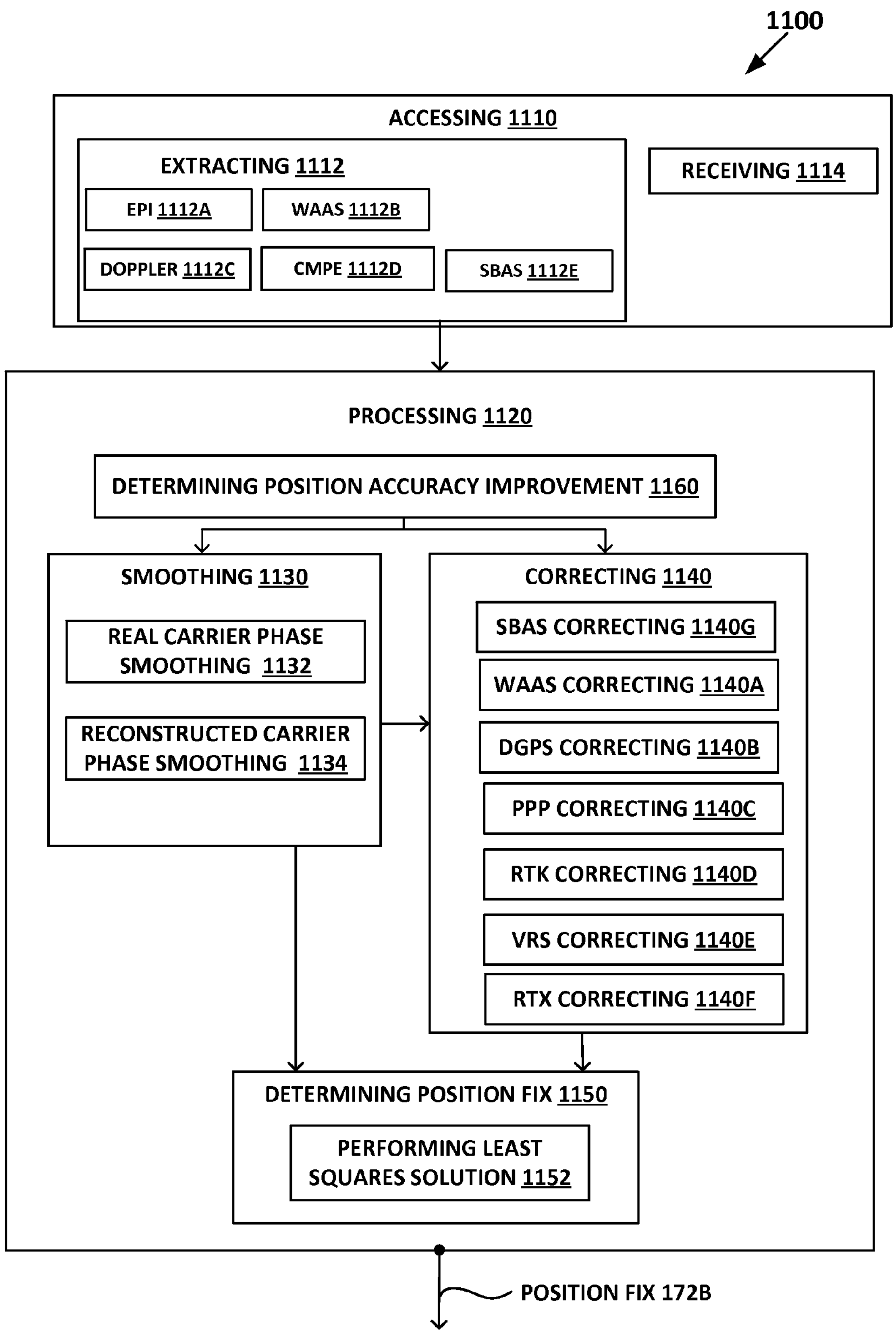
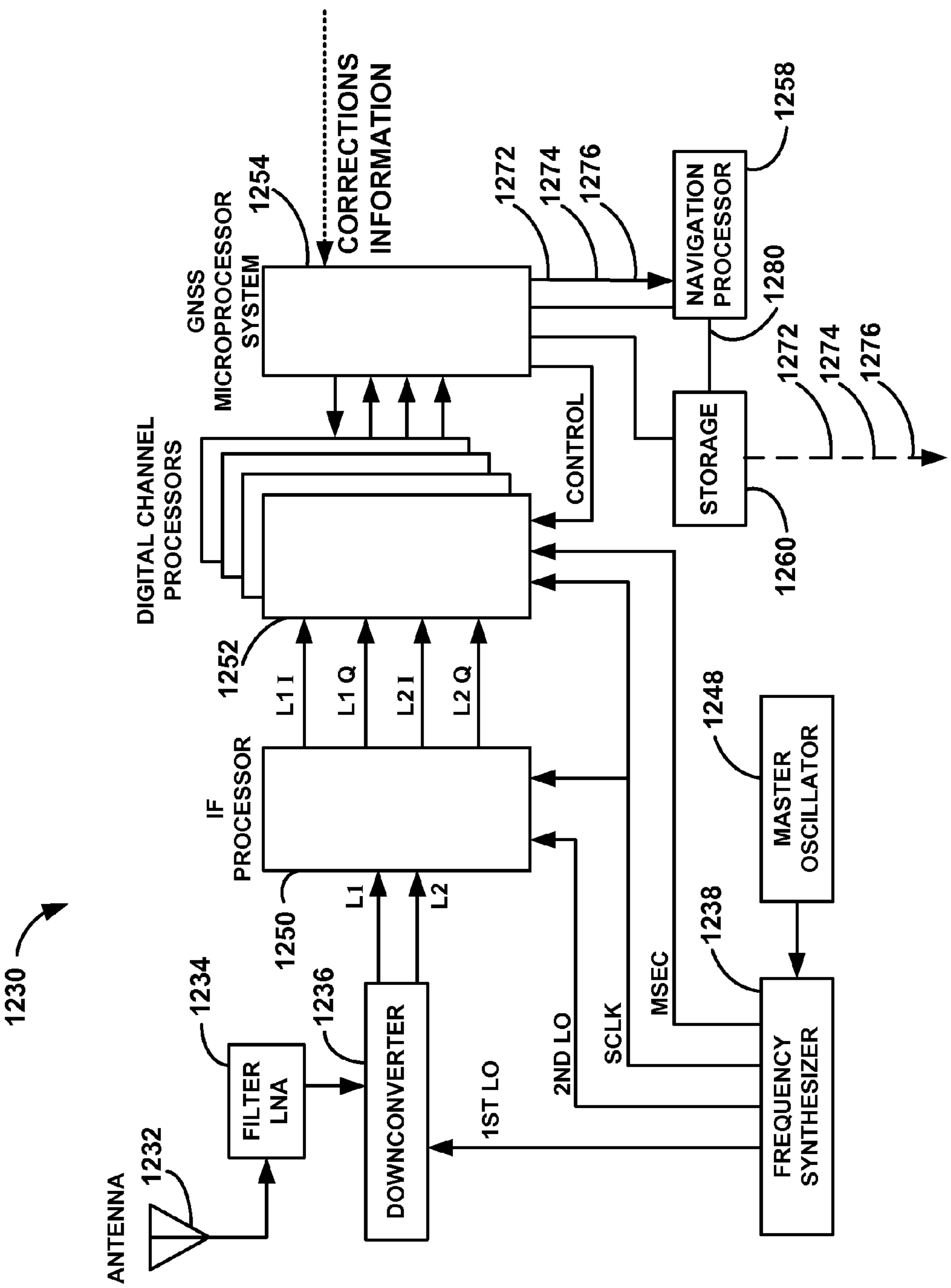

1100
ACCESSING 1110
EXTRACTING 1112
EPI 1112A
WAAS 1112B
DOPPLER 1112C
CMPE 1112D
SBAS 1112E
RECEIVING 1114
PROCESSING 1120
DETERMINING POSITION ACCURACY IMPROVEMENT 1160
SMOOTHING 1130
REAL CARRIER PHASE SMOOTHING 1132
RECONSTRUCTED CARRIER PHASE SMOOTHING 1134
CORRECTING 1140
SBAS CORRECTING 1140G
WAAS CORRECTING 1140A
DGPS CORRECTING 1140B
PPP CORRECTING 1140C
RTK CORRECTING 1140D
VRS CORRECTING 1140E
RTX CORRECTING 1140F
DETERMINING POSITION FIX 1150
PERFORMING LEAST SQUARES SOLUTION 1152
POSITION FIX 172B

FIG. 11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ANTENNA
1232
FILTER LNA
1234
DOWNCONVERTER
1236
1ST LO
2ND LO
SCLK
MSEC
1238
FREQUENCY SYNTHESIZER
MASTER OSCILLATOR
1248
L1
L2
1250
IF PROCESSOR
L1 I
L1 Q
L2 I
L2 Q
1252
DIGITAL CHANNEL PROCESSORS
CONTROL
GNSS MICROPROCESSOR SYSTEM
1254
CORRECTIONS INFORMATION
1272
1274
1276
NAVIGATION PROCESSOR
1258
1280
STORAGE
1260
1272
1274
1276

FIG. 12

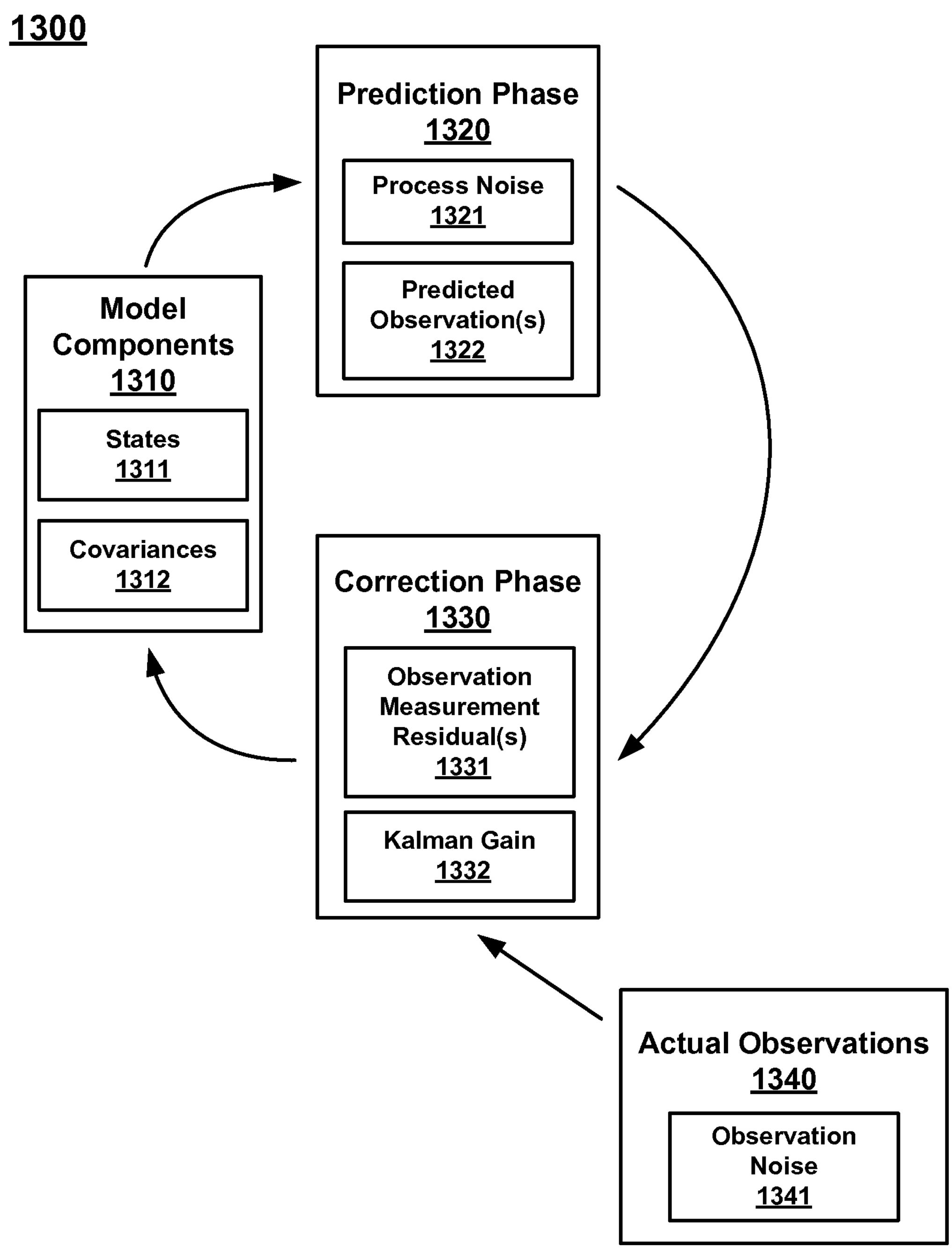
1300
Prediction Phase
1320
Process Noise
1321
Predicted
Observation(s)
1322
Model
Components
1310
States
1311
Covariances
1312
Correction Phase
1330
Observation
Measurement
Residual(s)
1331
Kalman Gain
1332
Actual Observations
1340
Observation
Noise
1341

Fig. 13

EXTRACTING PSEUDORANGE INFORMATION USING A CELLULAR DEVICE

CROSS-REFERENCE TO RELATED U.S. APPLICATIONS

This application claims priority to and benefit of U.S. Provisional Patent Application No. 61/746,916, filed on Dec. 28, 2012, entitled "IMPROVED GPS/GNSS ACCURACY FOR A CELL PHONE," by Rudow et al., and assigned to the assignee of the present application; the contents of U.S. Provisional Patent Application No. 61/746,916 are hereby incorporated herein by reference.

This application is a continuation-in-part application of and claims priority to and benefit of co-pending U.S. patent application Ser. No. 13/842,447, filed on Mar. 15, 2013, entitled "OBTAINING PSEUDORANGE INFORMATION USING A CELLULAR DEVICE," by Rudow et al., and assigned to the assignee of the present application; the contents of U.S. patent application Ser. No. 13/842,447 are hereby incorporated herein by reference.

BACKGROUND

The Global Positioning System (GPS) and its extensions in the Global Navigation Satellite Systems (GNSS) have become thoroughly pervasive in all parts of human society, worldwide. GPS and GNSS receivers in the form of chipsets have become widely incorporated into cell phones and other types of cellular devices with cellular-based communications equipment.

Typically, cellular devices include highly integrated GNSS chipsets that are designed to work with the E-911 service primarily, and are not designed to provide anywhere near a full range of features and outputs. They do provide a position fix, but are not designed to make available very many other parameters of interest. All GNSS receivers must acquire, track and decode a data message that conveys information about the location of the satellites in space, and time information. The principal additional parameter obtained is the "pseudorange." However, conventionally, this set of data is not available as an output from the cell phone GNSS chipsets for use by the cellular device itself. Conventionally, in circumstances where it is available, it is under access control by the vendor.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings, which are incorporated in and form a part of this application, illustrate embodiments of the subject matter, and together with the description of embodiments, serve to explain the principles of the embodiments of the subject matter. Unless noted, the drawings referred to in this brief description of drawings should be understood as not being drawn to scale. Herein, like items are labeled with like item numbers.

FIG. **1**A depicts a block diagram of a cellular device for extracting pseudorange information, according to one embodiment.

FIG. **1**B depicts a block diagram of a cellular device for extracting and processing pseudorange information, according to one embodiment.

FIG. **1**C depicts decision logic for determining whether to apply WAAS (Wide Area Augmentation System) corrections or DGPS (Differential Global Positioning System) corrections, according to one embodiment.

FIG. **1**D depicts a block diagram of a cellular device for extracting pseudorange information, according to one embodiment.

FIG. **2** depicts a block diagram of multiple sources for providing positioning correction information to a cellular device for processing pseudorange information, according to one embodiment.

FIG. **3** depicts a conceptual view of pseudorange measurements, according to various embodiments.

FIG. **4** depicts a flowchart for determining an RTK (Real Time Kinematic) position solution, according to one embodiment.

FIG. **5**A is a flowchart of a method for performing a carrier phase smoothing operation using real carrier phase information, according to one embodiment.

FIG. **5**B is a flowchart of a method for generating reconstructed carrier phase information based on Doppler shift, according to one embodiment.

FIG. **6** depicts a flowchart of a method of extracting pseudorange information using a cellular device, according to one embodiment.

FIGS. **7**A-**10** depict flowcharts of methods of improving the position accuracy using one or more position accuracy improvements, according to various embodiments.

FIG. **11** depicts a flowchart a method of accessing and processing extracted pseudorange information, according to one embodiment.

FIG. **12** depicts a block diagram of a GNSS receiver, according to one embodiment.

FIG. **13** depicts an example Kalman filtering process, according to some embodiments.

DESCRIPTION OF EMBODIMENTS

Reference will now be made in detail to various embodiments of the subject matter, examples of which are illustrated in the accompanying drawings. While various embodiments are discussed herein, it will be understood that they are not intended to limit to these embodiments. On the contrary, the presented embodiments are intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope the various embodiments as defined by the appended claims. Furthermore, in the following Description of Embodiments, numerous specific details are set forth in order to provide a thorough understanding of embodiments of the present subject matter. However, embodiments may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the described embodiments.

Unless specifically stated otherwise as apparent from the following discussions, it is appreciated that throughout the description of embodiments, discussions utilizing terms such as "accessing," "calculating," "extracting," "using," "providing," "applying," "correcting," "smoothing," "reconstructing," "modeling," "improving," "processing," "determining," "selecting," "determining," "locating," "positioning," "increasing," "accessing," "differentiating," "integrating," "bridging," displaying," "performing," "providing," "obtaining," "calculating," "receiving," "storing," "notifying," "matching," "creating," "generating," "communicating," "transmitting," "requesting," "providing," "activating, "deactivating," "initiating," "terminating," "causing," "transforming data," "modifying data to transform the state of a computer system," or the like, refer to the actions and processes of a computer system, data storage system, storage system controller, microcontroller, hardware processor, or similar electronic computing device or combination of such electronic computing devices. The computer system or similar electronic computing device manipulates and transforms data represented as physical (electronic) quantities within the computer system's/device's registers and memories into other data similarly represented as physical quantities within the computer system's/device's memories or registers or other such information storage, transmission, or display devices.

Overview

Cellular devices, such as cell phones and non-voice enabled cellular devices, possesses pseudorange information that can be used in surveying and other positioning operations. Conventionally, however, the pseudorange information from cellular device chipsets are only available under a limited set of conditions, usually only when performing a E-911 service call, and then only for use by the Assisted GPS service located in conjunction with the E-911 service facility. Therefore, according to one embodiment, an embedded GNSS chipset is employed with in a cellular device, which: a) calculates pseudorange information for use by the GNSS chipset; and b) permits extraction of this pseudorange information by the cellular device in which it is embedded. As will be discussed, the pseudorange information from the GNSS chipset is extracted for use elsewhere in the cellular device outside of the GNSS chipset.

Examples of Systems for Extracting Pseudorange Information

FIG. **1**A depicts a block diagram of a cellular device **100** for extracting pseudorange information, according to one embodiment. Examples of a cellular device **100** include a cell phone, a non-voice enabled cellular device, and a mobile hand-held GNSS receiver. The cellular device may be mobile or stationary. The cellular device may be hand-holdable or incorporated as a portion of a system which is not hand-holdable. In some embodiments, a cellular device, such as cellular device **100**, may be utilized as a portion of a navigation system, security system, safety system, telematics device/box, or the like. In some embodiments, cellular device **100** may be utilized as sub-system of the vehicle mounted portion of a vehicle safety system, security system, and/or navigation system. The vehicle mounted portion of the OnStar® vehicle safety, vehicle security, and vehicle navigation system that is utilized in many vehicles is one non-limiting example of a system which may include cellular device **100**.

As depicted in FIG. **1**A, the cellular device **100** includes a GNSS chipset **170**, a GNSS receiver **107**, a processor **172** that is part of the GNSS receiver **107**, a chipset accessor logic **141**, a pseudorange information extractor logic **142**, an improved accuracy Secure User Platform Location (SUPL) client **101**, a pseudorange information bridger logic **143**, a pseudorange information processing logic **150**, an operating system **160**, a location manager logic **161**, a location displayer logic **162**, hardware **180** that is outside of the GNSS receiver **107**. According to one embodiment, the chipset accessor logic **141**, the pseudorange information extractor logic **142**, the pseudorange information processing logic **150**, and the pseudorange information bridger logic **143** are a part of the improved accuracy SUPL client **101**.

According to one embodiment, the hardware **180** includes a hardware processor **109** and memory **210**. An example of a hardware processor **109** is a central processing unit. An example of hardware memory **210** is computer readable storage, such as, but not limited to, a disk, a compact disk (CD), a digital versatile device (DVD), random access memory (RAM) or read only memory (ROM). The hardware memory **210** is physical and, therefore, tangible, according to one embodiment. The hardware memory **210**, according to another embodiment, is non-transitory.

According to one embodiment, the processor **172** and the GNSS receiver **107** are a part of the GNSS chipset **170**. According to one embodiment, the chipset accessor logic **141**, pseudorange information extractor logic **142**, the pseudorange information bridger logic **143**, the improved accuracy SUPL client **101**, the operating system **160**, and the processor **109** are located in a portion of the cellular device **100** that is outside of the GNSS chipset **170**. The location manager logic **161** can be a part of the operating system **160** and external to the GNSS chipset **170**. According to one embodiment, the location displayer logic **162** is a part of the location manager logic **161**. According to one embodiment, the chipset accessor logic **141**, pseudorange information extractor logic **142**, the pseudorange information processing logic **150**, pseudorange information bridger logic **143**, and improved accuracy SUPL client **101** are application programming interfaces (API) function applications that reside in memory of the cellular device **100** and are executed by a processor **109** of the cellular device **100**.

According to one embodiment, the GNSS receiver **107** is capable of receiving signals from GPS satellites, GLONASS satellites, or from a combination of satellites from different constellations. The GNSS receiver **107** can perform GPS measurements to derive raw measurement data for a position of the cellular device **100**. The raw measurement data can provide an instant location of the cellular device **100**. According to one embodiment, the raw measurement data is the pseudorange information that is extracted (also referred to as "extracted pseudorange information"). Examples of the extracted pseudorange information are uncorrected pseudorange information, observed pseudorange information, or unsmoothed pseudorange information, or a combination thereof. Conventionally, the raw measurement data is only for use by the GNSS chipset **170** and the GNSS chipset **170** calculates pseudorange information that is only for use by the GNSS chipset **170**. Examples of pseudorange information are uncorrected pseudorange information, smoothed pseudoranges, and corrected pseudoranges. Examples of corrections used to improve accuracy of a position fix include differential GNSS corrections (DGPS), high precision GNSS satellite orbital data, GNSS satellite broadcast ephemeris data, and ionospheric and tropospheric error corrections and error projections based on location.

The GNSS chipset **170** has a processor **172** and, therefore, is capable of processing information, such as pseudorange information, itself. However, according to various embodiments, information that the GNSS chipset **170** has can be extracted from the GNSS chipset **170** and processed outside of the GNSS chipset **170** instead of by the GNSS chipset **170** using its own processor **172**, in order to provide an improved accuracy position fix.

The chipset accessor logic **141** is configured for accessing the GNSS chipset **170**. The pseudorange information extractor logic **142** is configured for extracting the pseudorange information from the accessed GNSS chipset **170**. The extracted pseudorange information can be received and stored continuously. The pseudorange information bridger logic **143** is configured for bridging the pseudorange information from the GNSS chipset **170** to the location manager logic **161** that resides in the operating system **160** of the cellular device **100**.

According to one embodiment, the chipset accessor logic **141**, the pseudorange information extractor logic **142**, the pseudorange information processing logic **150** and pseudorange information bridger logic **143** are a part of an improved accuracy SUPL client **101**. For example, The SUPL client **101** can interface between the GNSS chipset **170** and the location manager logic **161**, which resides in the operating system **160**.

The pseudorange information can be obtained from the processor **172** of the GNSS receiver **107**. The GNSS chipset **170** may be designed, for example, by the manufacturer of the GNSS chipset **170**, to provide requested information, such as pseudorange information, in response to receiving the command. The pseudorange information may be extracted from the GNSS chipset **170** using the command that the manufacturer has designed the GNSS chipset **170** with. For example, according to one embodiment, the GNSS chipset **170** is accessed using an operation that is a session started with a message that is an improved accuracy Secure User Platform Location (SUPL) start message or a high precision SUPL INIT message. According to one embodiment, the message is a custom command that is specific to the GNSS chipset **170** (also referred to as "a GNSS chipset custom command") and by which the improved accuracy SUPL client **101** can gain access to the raw measurements of the GNSS chipset **170**. Access may be controlled by the chipset manufacturer and a suitable key made available for use in the SUPL for obtaining access to the pseudoranges. A suitable key is an example of a "custom command."

A worker thread associated with the SUPL client **101** can monitor the raw measurements delivered by the GNSS chipset **170** into the GNSS chipset **170**'s memory buffers, cache the raw measurements and use the raw measurements to determine a position fix. The pseudorange information extractor logic **142** and the pseudorange information processing logic **150** can be associated with the worker thread. For example, the pseudorange information extractor logic **142** can cache the raw measurements and the pseudorange information processing logic **150** can determine the location.

According to one embodiment, a worker thread is a light weight process that executes a specific sequence of tasks in the background. The tasks can be of long term and/or at times periodic in nature. The worker thread can assist in helping the main thread, which may also be referred to as the main program or main task, with specific functions. Worker threads can be started when these functions of the sequence of tasks are to be executed. A worker thread can remain in the active state as long as its respective functions are being executed. A worker thread may terminate itself, when it completes its functions or when it reaches a point where it can no longer continue to function, for example, due to an irrecoverable error. A worker thread can post its status to the main thread when it ends. Examples of posted status are completion or termination. A worker thread may also post to the main thread the level of progress of its functions periodically. At a given point in time, there may be many such worker threads in progress at the same time. Worker threads may maintain some sort of synchronization amongst themselves depending upon the tasks they are intended for. The main thread may terminate a worker thread, for example, when the functions of that worker thread are no longer needed or due to other execution changes in the system.

According to one embodiment, the cellular device **100** can improve the accuracy of the extracted pseudorange information. For example, the pseudorange information processing logic **150** can improve the accuracy of the extracted pseudorange information, as will become more evident.

The output of the pseudorange information processing logic **150** can be used for determining the location of the cellular device **100**. For example, a latitude, longitude and altitude can be determined based on the output of the pseudorange information processing logic **150**, which can be displayed by the location displayer logic **162**.

According to one embodiment, the pseudorange information bridger logic **143** communicates the output from the pseudorange information processing logic **150** to the location manager logic **161** in the operating system **160**. According to one embodiment, the output of the pseudorange information processing logic **150** is a location that is defined in terms of latitude, longitude, and altitude. The methods are well-known in the GPS arts. The pseudoranges are used to first determine a location the WGS-84 coordinate system of the Global Positioning System, and then converted into latitude, longitude, and elevation.

The location displayer logic **162** can display the location with respect to a digital representation of a map available, for example, from third parties via download to the cellular device.

FIG. **1**B depicts a block diagram of a portion of a cellular device **100**, **100**D for extracting pseudorange information, according to one embodiment. The cellular device **100**, **100**D includes accessing-logic **110**B and processing logic **150**. The accessing logic **110**B includes extracting logic **112**B and receiving logic **114**B. The extracting logic **112**B includes pseudorange information extracting logic **142**, satellite-based augmentation system (SBAS), extracting logic **112**B-**5**, WAAS extracting logic **112**B-**2**, Doppler shift extracting logic **112**B-**3**, and carrier phase measurement extracting logic **112**B-**4**. According to one embodiment, WAAS is an example of SBAS. According to one embodiment, SBAS extracting logic **112**B-**5** includes WAAS extracting logic **112**B-**2**.

Examples of satellite-based augmentation system (SBAS) are Indian GPS aided Geo Augmented Navigation System (GAGAN), European Geostationary Navigation Overlay Service (EGNOS), Japanese Multi-functional Satellite Augmentation System (MSAS), John Deere's StarFire, WAAS, and Trimble's OmniStar.

As depicted in FIG. **1**B, the pseudorange information processing logic **150** includes pseudorange-correction-logic **151**, pseudorange-carrier-phase-smoothing-logic **152**, position accuracy improvement determination logic **180**B and determining position fix logic **170**B. Examples of "improving" are "smoothing" or "correcting," or a combination thereof. The pseudorange-correction-logic **151** includes WAAS logic **151**A, DGPS logic **151**B, Precise Point Positioning (PPP) logic **151**C, RTK logic **151**D, VRS (Virtual Reference Station) logic **151**E, and RTX logic **151**F. The pseudorange-carrier-phase-smoothing-logic **152** includes real carrier phase logic **152**A and reconstructed carrier phase logic **152**B. According to one embodiment, the accessing-logic **110**B and the processing logic **150** reside in the improved accuracy SUPL client **101**.

Examples of pseudorange information are extracted pseudoranges, corrected pseudoranges, smoothed pseudoranges, or a combination thereof, among other things. Examples of pseudorange corrections include Wide Area Augmentation System (WAAS) corrections, Differential Global Positioning System (DGPS) corrections, Precise Point Positioning (PPP) corrections, Real Time Kinematic (RTK) corrections, and Virtual Reference Station (VRS) corrections. Examples of carrier phase information include real carrier phase and reconstructed carrier phase information.

The extracting logic **112**B can extract various types of information from the GNSS chipset **170**, as discussed herein. For example, the extracting logic **112**B includes pseudorange information extracting logic **142**, WAAS extracting logic **112**B-**2**, Doppler extracting logic **112**B-**3**, and carrier phase measurement extracting logic **112**B-**4**. According to one embodiment, the extracting logic **112**B can be used to extract these various types of information from the GNSS chipset **170** in a similar manner that the pseudorange information extractor logic **142** extracts pseudorange information from the GNSS chipset **170**, for example, using an SUPL Client **101** that employs a command designed or provided by the manufacturer of the GNSS chipset **170**, as described herein. More specifically, the WAAS extracting logic **112**B-**2**, the Doppler extracting logic **112**B-**3**, and carrier phase measurement extracting logic **112**B-**4** can employ commands designed or provided by the manufacturer of the GNSS chipset **170** to extract respectively WAAS, Doppler information, and carrier phase measurements for real carrier phase information.

The receiving logic **114**B receives other types of information that are not extracted from the GNSS chipset **170**. The receiving logic **114**B can receive the information in response to a request (also commonly known as "pulling") or receive the information without the information being requested (also commonly known as "pushing"). "Obtaining" and "accessing" can be used interchangeably, according to various embodiments.

Table 1 depicts the types of information that are extracted from the GNSS chipset or received without extraction, as discussed herein, according to various embodiments.

TABLE 1

Types of Information that are Extracted from the GNSS Chipset or Received without Extraction

Extracted	Received
Pseudorange Information	WAAS/SBAS
Doppler Shift Information	DGPS
Carrier Phase Measurements for real carrier phase information	RTK
WAAS/SBAS	Not Applicable

The information depicted in the extracted column can be extracted from the GNSS chipset **170** using the SUPL client **101** in a manner similar to extracting pseudorange information, as discussed herein. WAAS may be extracted or received, for example, over the Internet. When this Doppler shift information is available but real carrier phase information is not, the extracted Doppler shift information can be integrated by processor **109**, for example, to reconstruct carrier phase information. Techniques for reconstructing carrier phase information from Doppler shift information are well known in the art. Any one or more of the information depicted in Table 1 can be processed by the cellular device **100**, for example, using the processor **109** that is outside of the GNSS chipset **170**.

The pseudorange-carrier-phase-smoothing-logic **152** can smooth pseudorange information by applying carrier phase information to the pseudorange information.

The pseudorange-carrier-phase-smoothing-logic **152** receives raw pseudorange information from the accessing logic **110**B. The carrier phase information may be reconstructed carrier phase information or real carrier phase information.

The pseudorange-correction-logic **151** can correct pseudorange information. For example, the pseudorange-correction-logic **151** can receive pseudorange information and apply pseudorange corrections to the pseudorange information. Examples of the pseudorange information received by the pseudorange-correction-logic **151** include extracted pseudorange information, DGPS corrected pseudoranges, and smoothed pseudoranges that were smoothed, for example, using either real carrier phase information or reconstructed carrier phase information. Examples of pseudorange corrections that can be applied to the received pseudorange information are WAAS corrections, DGPS corrections, PPP corrections, RTK corrections and VRS corrections. The PPP logic **151**C performs Precise Point Positioning (PPP) processing on pseudorange information. According to one embodiment, RTX™ is proprietary form of PPP developed by Trimble Navigation Limited. It should be appreciated that there are other forms of Precise Point Positioning which may operate using similar principles.

The pseudorange information processing logic **150** may also include a determining position fix logic **170**B that performs, for example, a least squares solution **171**B can be performed after the extracted pseudorange information is improved by the pseudorange-correction-logic **151** or the pseudorange-carrier-phase-smoothing-logic **152**, or a combination thereof and prior to transmitting the output to the pseudorange information bridger logic **143**. According to one embodiment, the determining position fix logic **170**B resides in the processing logic **150**. Least-squares solution methods are well-known in the position determination arts.

According to one embodiment, extracted pseudorange information is passed from the extracting pseudorange information logic **142** to the smoothing logic **152** where it is smoothed at either real carrier phase logic **152**A or reconstructed carrier phase logic **152**B. According to one embodiment, the smoothed pseudorange information is communicated from the smoothing logic **152** to the correcting logic **151** for further correction, where one or more corrections may be performed. If a plurality of corrections is performed, they can be performed in various combinations. If carrier phase smoothing is not possible, the extracted pseudorange information can be communicated from extracting pseudorange information logic **142** to correction logic **151**. One or more of the logics **152**A, **152**B, **151**A, **151**E, **151**F in the processing logic **150** can communicate with any one or more of the logics **152**A, **152**B, **151**A, **151**E **151**F in various orders and combinations. Various embodiments are not limited to just the combinations and orders that are described herein. According to one embodiment, extracted pseudorange information may not be smoothed or corrected. In this case, unsmoothed uncorrected pseudorange information can be communicated from logic **142** to logic **170**B.

The cellular device **100** may also include a position-accuracy-improvement-determination-logic **180**B for determining whether to apply any improvements and if so, the one or more position accuracy improvements to apply to the extracted pseudorange information. For example, the cellular device **100** may be preconfigured based on the signals that are available to the cellular device **100** or a user of the cellular device **100** may manually configure the cellular device **100**. For example, the cellular device **100** can display the signals that are available to the user and the user can select which signals they desire from the displayed list of signals. The configuration information, whether preconfigured or manually configured by the user, can be stored for example, in a look up table in the cellular device **100**. Examples of position improvements that can be determined by the position accuracy improvement determination logic **180**B are real carrier phase information, reconstructed carrier phase information, WAAS, DGPS, PPP, RTX™, RTK and VRS. The position accuracy improvement determination logic **180**B can be used to determine to reconstruct carrier phase information based on Doppler shift if real carrier phase information is not available, for example. The position-accuracy-improvement-determination-logic **180**B, according to one embodiment, is a part of the SUPL client **101**.

Extracted pseudorange information without any additional improvements provides 4-5 meters of accuracy. Various combinations of position accuracy improvements can be applied to extracted pseudorange information (EPI) according to various embodiments, where examples of position accuracy improvements include, but are not limited to, Wide Area Augmentation System (WAAS) pseudorange corrections, Differential GPS (DGPS) pseudorange corrections, Precise Point Positioning (PPP) processing, RTX™, Real Time Kinematic (RTK), Virtual Reference Station (VRS) corrections, real carrier phase information (real CPI) smoothing, and reconstructed carrier phase information (reconstructed CPI) smoothing.

One or more of the logics **110**B, **112**B, **114**B, **142**, **112**B-**2**, **112**B-**3**, **180**B, **152**, **152**A, **152**B, **151**, **151**Aj-**151**F, **170**B, **171**B can be executed, for example, by the processor **109** of the cellular device **100** that is located outside of the GNSS chipset **170**.

Table 2 depicts combinations of information that result in a position fix **172**B, according to various embodiments. However, various embodiments are not limited to the combinations depicted in Table 2.

TABLE 2

Combinations of Information that Result in a Position Fix

Combination Identifier	Combinations of Information that Result in a Position Fix
1	Extracted pseudorange information (EPI)
2	EPI + Real or Reconstructed Carrier Phase Information (CPI)
3	EPI + CPI + WAAS
4	EPI + CPI + WAAS + DGPS
5	EPI + CPI + DGPS
6	EPI + CPI + DGPS + PPP
7	EPI + DGPS
8	EPI + DGPS + WAAS
9	EPI + DGPS + PPP
10	EPI + RTK
11	EPI + VRS

FIG. **1**C depicts decision logic **151**H for determining whether to apply SBAS corrections **151**G, WAAS corrections **151**A, PPP corrections **151**C, RTX™ corrections **151**F or DGPS corrections **151**B, according to one embodiment. According to one embodiment, the SBAS corrections that are applied are WAAS corrections. According to one embodiment, the decision logic **151**H is located in the position accuracy improvement determination logic **180**B or the correction logic **151**.

According to one embodiment, a first position is determined by an available means. For example, the first position may be based on uncorrected unsmoothed extracted pseudorange information, cellular tower triangulation, WiFi triangulation or other means. A level of precision may be selected, for example, by a user or preconfigured into the cellular device, where DGPS or one or more of SBAS, WAAS, RTX™, PPP would be used to achieve that level of precision. The decision logic **151**H can access the level of precision and receive two or more reference station locations by sending a message to a database enquiring about nearby reference stations for DGPS. The decision logic **151**H can determine the distance between the cellular device **100** and the nearest reference station. If the distance is greater than some selected distance threshold, the decision logic **151**H can use PPP, RTX™, SBAS or WAAS, instead of DGPS. If the distance is less than the selected distance threshold, the decision logic **151**H can use DGPS instead of PPP, RTX™, SBAS or WAAS. According to one embodiment, a range for a distance threshold is approximately 20 to 60 miles. According to one embodiment, the distance threshold is approximately 60 miles.

If the decision logic **151**H determines to apply DGPS corrections at DGPS logic **151**B resulting in DGPS corrected smoothed pseudoranges, further corrections can be made using the orbit-clock information contained in the PPP corrections. For example, a position fix can be determined based on the DGPS corrected smoothed pseudoranges and the PPP corrections. The position fix can be determined external to the GNSS chipset, for example, at the processing logic **150**.

The cellular device **100** may be configured with the distance threshold, for example, by the manufacturer of the cellular device **100** or by a user of the cellular device **100**. The cellular device **100** may be configured with the distance threshold through service that is remote with respect to the cellular device **100** or may be configured locally. The distance threshold can be selected based on a degree of position accuracy that is desired.

FIG. **1**D depicts a block diagram of a cellular device **100**D for extracting pseudorange information, according to one embodiment.

As depicted in FIG. **1**D, the GNSS chipset **170** is located on a system on a chip (SOC) substrate (SOCS) **190**.

As described herein, various information can be extracted from the GNSS receiver **1130**, such as pseudorange information, Doppler Shift Information, Real Carrier Phase Measurement, WAAS and SBAS. Other types of processing information output by the GNSS receiver **1130** can be ignored.

A Cell device **100**D's hardware architecture includes discreet physical layout and interconnection of multiple chipsets for processing and for special purposes such as a GNSS chipset **170**. In addition, newer architectures involve further integration of chipsets in the "system on a chip" (SoC) configuration. In this configuration, the GNSS chipset **170** can still be a complete element capable of delivering a PVT (position velocity and time) solution. However in an embodiment, the pseudorange information, carrier phase, and/or Doppler measurements, along with WAAS corrections if available, are extracted prior to further signal processing in the GNSS chipset **170** and are processed using different algorithms and corrections data for developing an improved accuracy PVT solution. In so doing the deleterious effects of multipath and other error sources may be minimized. Further the GNSS chipset **170** outputs are ignored and not displayed when the external processing is employed and the higher-accuracy PVT data is available.

FIG. **2** depicts a block diagram of a set of correction delivery options for providing positioning information to a cellular device for extracting pseudorange information, according to one embodiment. Examples of a cellular device **200** include a cell phone, a non-voice enabled cellular device, and a mobile hand-held GNSS receiver. The cellular device may be mobile or stationary.

The cellular device **200** includes a bus **216**, a satellite receiver **206**, a GNSS receiver **107**, an FM radio receiver **208**, a processor **109**, memory **210**, a cellular transceiver **211**, a display **212**, audio **213**, Wi-Fi transceiver **214**, IMU **215**, image capturing device **240**, and operating system **160**. Components **206**, **107**, **208**, **109**, **210**, **211**, **212**, **213**, **214**, **215**, and **240** are all connected with the buss **216**.

In FIG. **2**, a plurality of broadcast sources is used to convey data and media to a cellular device **200**. As an example, cellular device **200** can receive broadcast signals from communication satellites **201** (e.g., two-way radio, satellite-based cellular such as the Inmarsat or Iridium communication networks, etc.), global navigation satellites **202** which provide radio navigation signals (e.g., the GPS, GNSS, GLONASS, GALILEO, BeiDou, Compass, etc.), and terrestrial radio broadcast (e.g., FM radio, AM radio, shortwave radio, etc.)

A cellular device **200** can be configured with a satellite radio receiver **206** coupled with a communication bus **216** for receiving signals from communication satellites **201**, a GNSS receiver **107** coupled with bus **216** for receiving radio navigation signals from global navigation satellites **202** and for deriving a position of cellular device **200** based thereon. Cellular device **200** further comprises an FM radio receiver **208** coupled with bus **216** for receiving broadcast signals from terrestrial radio broadcast **203**. Other components of cellular device **200** comprise a processor **109** coupled with bus **216** for processing information and instructions, a memory **210** coupled with bus **216** for storing information and instructions for processor **109**. It is noted that memory **210** can comprise volatile memory and non-volatile memory, as well as removable data storage media in accordance with various embodiments. Cellular device **200** further comprises a cellular transceiver **211** coupled with bus **216** for communicating via cellular network **222**. Examples of cellular networks used by cellular device **200** include, but are not limited to GSM: cellular networks, GPRS cellular networks, GDMA cellular networks, and EDGE cellular networks. Cellular device **200** further comprises a display **212** coupled with bus **216**. Examples of devices which can be used as display **212** include, but are not limited to, liquid crystal displays, LED-based displays, and the like. It is noted that display **212** can be configured as a touch screen device (e.g., a capacitive touch screen display) for receiving inputs from a user as well as displaying data. Cellular device **200** further comprises an audio output **213** coupled with bus **216** for conveying audio information to a user. Cellular device **200** further comprises a Wi-Fi transceiver **214** and an inertial measurement unit (IMU) **215** coupled with bus **216**. Wi-Fi transceiver **114** may be configured to operate on any suitable wireless communication protocol including, but not limited to WiFi, WiMAX, implementations of the IEEE 802.11 specification, implementations of the IEEE 802.15.4 specification for personal area networks, and a short range wireless connection operating in the Instrument Scientific and Medical (ISM) band of the radio frequency spectrum in the 2400-2484 MHz range (e.g., implementations of the Bluetooth® standard).

Improvements in GNSS/GPS positioning may be obtained by using reference stations with a fixed receiver system to calculate corrections to the measured pseudoranges in a given geographical region. Since the reference station is located in a fixed environment and its location can be determined very precisely via ordinary survey methods, a processor associated with the Reference Station GNSS/GPS receivers can determine more precisely what the true pseudoranges should be to each satellite in view, based on geometrical considerations. Knowing the orbital positions via the GPS almanac as a function of time enables this process, first proposed in 1983, and widely adopted ever since. The difference between the observed pseudorange and the calculated pseudorange for a given Reference station is called the pseudorange correction. A set of corrections for all the global navigation satellites **202** in view is created second by second, and stored, and made available as a service, utilizing GPS/GNSS reference stations **220** and correction services **221**. The pseudoranges at both the cellular device **200** GPS receiver **107** and those at the reference stations **220** are time-tagged, so the corrections for each and every pseudorange measurement can be matched to the local cell phone pseudoranges. The overall service is often referred to as Differential GPS, or DGPS. Without any corrections, GNSS/GPS receivers produce position fixes with absolute errors in position on the order of 4.5 to 5.5 m per the GPS SPS Performance Standard, 4th Ed. 2008. In FIG. **2**, one or more correction services **221** convey these corrections via a cellular network **222**, or the Internet **223**. Internet **223** is in turn coupled with a local Wi-Fi network **224** which can convey the corrections to cellular device **200** via Wi-Fi transceiver **214**. Alternatively, cellular network **222** can convey the corrections to cellular device **200** via cellular transceiver **211**. In some embodiments, correction services **221** are also coupled with a distribution service **225** which conveys the corrections to an FM radio distributor **226**. FM radio distributor **226** can broadcast corrections as a terrestrial radio broadcast **103**. It should be appreciated that an FM signal is being described as a subset of possible terrestrial radio broadcasts which may be in a variety of bands and modulated in a variety of manners. In some embodiments, cellular device **200** includes one or more integral terrestrial radio antennas associated with integrated terrestrial receivers; FM radio receiver **208** is one example of such a terrestrial receiver which would employ an integrated antenna designed to operate in the correct frequency band for receiving a terrestrial radio broadcast **103**. In this manner, in some embodiments, cellular device **200** can receive the corrections via FM radio receiver **208** (or other applicable type of integrated terrestrial radio receiver). In some embodiments, correction services **221** are also coupled with a distribution service **225** which conveys the corrections to a satellite radio distributor **227**. Satellite radio distributor **227** can broadcast corrections as a broadcast from one or more communications satellites **201**. In some embodiments, cellular device **200** includes one or more integral satellite radio antennas associated with integrated satellite radio receivers **206**. Satellite radio receiver **206** is one example of such a satellite receiver which would employ an integrated antenna designed to operate in the correct frequency band for receiving a corrections or other information broadcast from communication satellites **201**. In this manner, in some embodiments, cellular device **200** can receive the corrections via satellite radio receiver **206**.

Examples of a correction source that provides pseudorange corrections are at least correction service **221**, FM radio distribution **226**, or satellite radio distributor **227**, or a combination thereof. According to one embodiment, a correction source is located outside of the cellular device **200**.

Examples of image capturing device **240** are a camera, a video camera, a digital camera, a digital video camera, a digital camcorder, a stereo digital camera, a stereo video camera, a motion picture camera, and a television camera. The image capturing device **240** may use a lens or be a pinhole type device.

The blocks that represent features in FIGS. **1A-2** can be arranged differently than as illustrated, and can implement additional or fewer features than what are described herein. Further, the features represented by the blocks in FIGS. **1A-2** can be combined in various ways. A cellular device **100**, **200** (FIGS. **1A-3**) can be implemented using software, hardware, hardware and software, hardware and firmware, or a combination thereof. Further, unless specified otherwise, various embodiments that are described as being a part of the cellular device **100**, **200**, whether depicted as a part of the cellular device **100**, **200** or not, can be implemented using software, hardware, hardware and software, hardware and firmware, software and firmware, or a combination thereof. Various blocks in FIGS. **1A-2** refer to features that are logic, such as but not limited to, **150**, **180**B, **152**, **152**A, **152**B, **151**, **151**A-**151**G, **170**B, which can be; implemented using software, hardware, hardware and software, hardware and firmware, software and firmware, or a combination thereof.

The cellular device **100**, **200**, according to one embodiment, includes hardware, such as the processor **109**, memory **210**, and the GNSS chipset **170**. An example of hardware memory **210** is a physically tangible computer readable storage medium, such as, but not limited to a disk, a compact disk (CD), a digital versatile device (DVD), random access memory (RAM) or read only memory (ROM) for storing instructions. An example of a hardware processor **109** for executing instructions is a central processing unit. Examples of instructions are computer readable instructions for implementing at least the SUPL Client **101** that can be stored on a hardware memory **210** and that can be executed, for example, by the hardware processor **109**. The SUPL client **101** may be implemented as computer readable instructions, firmware or hardware, such as circuitry, or a combination thereof.

Pseudorange Information

A GNSS receiver **107** (also referred to as a "receiver"), according to various embodiments, makes a basic measurement that is the apparent transit time of the signal from a satellite to the receiver, which can be defined as the difference between signal reception time, as determined by the receiver's clock, and the transmission time at the satellite, as marked in the signal. This basic measurement can be measured as the amount of time shift required to align the C/A-code replica generated at the receiver with the signal received from the satellite. This measurement may be biased due to a lack of synchronization between the satellite and receiver clock because each keeps time independently. Each satellite generates a respective signal in accordance using a clock on board. The receiver generates a replica of each signal using its own clock. The corresponding biased range, also known as a pseudorange, can be defined as the transit time so measured multiplied by the speed of light in a vacuum.

There are three time scales, according to one embodiment. Two of the time scales are the times kept by the satellite and receiver clocks. A third time scale is a common time reference, GPS Time (GPST), also known as a composite time scale that can be derived from the times kept by clocks at GPS monitor stations and aboard the satellites.

Let τ be the transit time associated with a specific code transition of the signal from a satellite received at time t per GPST. The measured apparent range r, called pseudorange, can be determined from the apparent transmit time using equation 1 as follows:

$$\text{measured pseudorange at }(t)=c[\text{arrival time at }(t)-\text{emission time at }(t-\tau)]. \qquad \text{Eq. 1}$$

Both t and τ are unknown, and can be estimated. In this discussion of pseudoranges, measurements from a GPS satellite are dealt with in a generic way to make the notation simple, making no reference to the satellite ID or carrier frequency (L**1** or L**2**).

Equations 2 and 3 depict how to relate the time scales of the receiver and the satellite clocks with GPST:

$$\text{arrival time at }(t)=t+\text{receiver clock at }(t) \qquad \text{eq. 2}$$

$$\text{arrival time at }(t-\tau)=(t-\tau)+\text{satellite clock error at }(t-\tau) \qquad \text{eq. 3}$$

where receiver clock error represents the receiver **304**'s clock bias **303** and satellite clock error represents the bias **301** in the satellite **305**'s clock, and both the receiver clock and the satellite clock are measured relative to GPST **302**, as shown in FIG. **3**. Receiver clock error and satellite clock error represent the amounts by which the satellite **305** and receiver **304** clocks are advanced in relation to GPST. The satellite clock error **301** is estimated by the Control Segment and specified in terms of the coefficients of a quadratic polynomial in time. The values of these coefficients can be broadcast in the navigation message.

Accounting for the clock biases, the measured pseudorange (eq. 1) can be written as indicated in equation 4:

$$\begin{aligned}\text{PR}(t)&=c[t+\text{receiver clock error at }(t)-(t-\tau+\text{satellite clock error at }(t-\tau))]+\text{miscellaneous errors at }(t)\\&=c\tau+c[\text{receiver clock errors at }(t)-\text{satellite clock error at }(t-\tau)]+\text{miscellaneous errors at }(t)\end{aligned} \qquad \text{eq. 4}$$

where miscellaneous errors represent unmodeled effects, modeling error, and measurement error. The transmit time multiplied by the speed of light in a vacuum can be modeled as satellite position at (t−τ). Ionosphere error and troposphere error reflect the delays associated with the transmission of the signal respectively through the ionosphere and the troposphere. Both ionosphere error and troposphere error are positive.

For simplicity, explicitly reference to the measurement epoch t has been dropped, and the model has been rewritten for the measured pseudorange as indicated in equation 5.

$$\text{PR}=r+[\text{receiver clock error}-\text{satellite clock error}]+\text{ionosphere error}+\text{troposphere error}+\text{miscellaneous errors} \qquad \text{eq. 5}$$

where PR is the measured pseudorange, r is the true range from the receiver to the satellite, receiver clock error is the difference between the receiver clock and the GPSTIME, satellite clock error is the difference between the satellite clock and GPSTIME, GPSTIME is ultimately determined at the receiver as part of the least squared solution determined by the least squares solution **171**B so that all clock errors can be resolved to some level of accuracy as part of the position determination process, and miscellaneous errors include receiver noise, multipath and the like.

At least one source of error is associated with satellite positions in space. The navigation message in the GPS signal contains Keplerian parameters which define orbital mechanics mathematics and, thus, the positions of the satellites as a function of time. One component of WAAS and RTX™ contains adjustments to these parameters, which form part of the constants used in solving for the position fix at a given time. Taking account of the corrections is well-known in the GPS position determining arts.

Ideally, the true range r to the satellite is measured. Instead, what is available is PR, the pseudorange, which is a biased and noisy measurement of r. The accuracy of an estimated position, velocity, or time, which is obtained from these measurements, depends upon the ability to compensate for, or eliminate, the biases and errors.

The range to a satellite is approximately 20,000 kilometers (km) when the satellite is overhead, and approximately 26,000 km when the satellite is rising or setting. The signal transit time varies between about 70 millisecond (ms) and 90 ms. The C/A-code repeats each millisecond, and the code correlation process essentially provides a measurement of pseudo-transmit time modulo 1 ms. The measurement can be ambiguous in whole milliseconds. This ambiguity, however, is easily resolved if the user has a rough idea of his location within hundreds of kilometers. The week-long P(Y)-code provides unambiguous pseudoranges.

The receiver clocks are generally basic quartz crystal oscillators and tend to drift. The receiver manufacturers attempt to limit the deviation of the receiver clock from GPST, and schedule the typical once-per-second measurements at epochs that are within plus or minus 1 millisecond (ms) of the GPST seconds. One approach to maintaining the receiver clock within a certain range of GPST is to steer the receiver clock 'continuously.' The steering can be implemented with software. The second approach is to let the clock drift until it reaches a certain threshold (typically 1 ms), and then reset it with a jump to return the bias to zero.

An example of pseudorange measurements with a receiver using the second approach shall now be described in more detail. Assume that there are pseudorange measurements from three satellites which rose about the same time but were in different orbits. Assume that one comes overhead and stays in view for almost seven hours. Assume that the other two stay lower in the sky and could be seen for shorter periods. There are discontinuities common to all three sets of measurements due to the resetting of the receiver clock. A determination can be made as to whether the receiver clock is running fast or slow, and its frequency offset from the nominal value of 10.23 megahertz (MHz) can be estimated.

For more information on pseudorange information, refer to "Global Positioning Systems," by Pratap Misra and Per Eng, Ganga-Jamuna Press, 2001; ISBN 0-9709544-0-9.

Position Accuracy Improvements

The pseudorange information processing logic **150** can include various types of logic for improving the position accuracy of the extracted pseudorange information, as described herein. Table 2, as described herein, depicts various combinations of position accuracy improvements for improving extracted pseudorange information, according to various embodiments. Table 3 also depicts various combinations of position accuracy improvements for improving extracted pseudorange information, according to various embodiments.

TABLE 3

Various Combinations of Position Accuracy Improvements for Improving Extracted Pseudorange Information

Combination Identifier	Operation	Description	Accuracy
1	620 (FIG. 6)	Extracted Pseudorange Information (EPI)	4-5 meters (m)
2	720A (FIG. 7A)	EPI + WAAS	approx. 1.7 m
3	FIG. 7B	EPI + reconstructed CPI + WAAS	<1 m
4	820A (FIG. 8A)	EPI + DGPS	~1 m
5	830A (FIG. 8A)	EPI + DGPS + WAAS	<1 m
6	820B, 822B, 830B, 840B FIG. 8B	EPI + reconstructed CPI + DGPS + WAAS	<1 m
7	820B, 824B, 830B, 840B (FIG. 8B)	EPI + real CPI + DGPS + WAAS	<1 m
8	920A (FIG. 9A)	EPI + PPP	<1 m
9	930A (FIG. 9A)	EPI + PPP + DGPS	<1 m
10	FIG. 9B	EPI + reconstructed CPI + PPP + DGPS	<1 m
11	1020 and 1030 (FIG. 10)	EPI + CPI + PPP	<<1 m
12	1040 (FIG. 10)	EPI + CPI + PPP + DGPS	approx. 10 cm
13		EPI + RTK	approx. 2-10 cm

Table 3 includes columns for combination identifier, operation, description, and accuracy. The combination identifier column indicates an identifier for each combination of improvements. The operation column specifies operations of various flowcharts in FIGS. **6-10** for the corresponding combination. The description column specifies various combinations of position accuracy improvements that can be applied to extracted pseudorange information (EPI) according to various embodiments, where examples of position accuracy improvements include, but are not limited to, Wide Area Augmentation System (WAAS) pseudorange corrections, real carrier phase smoothing (real CPI) information, reconstructed carrier phase smoothing information (reconstructed CPI), Differential GPS (DGPS) pseudorange corrections, and Precise Point Positioning (PPP) processing. The accuracy column specifies levels of accuracy provided by the corresponding combination.

Combination 1 is extracted pseudorange information without any additional improvements, which provides 4-5 meters of accuracy. Combination 1 is described in Table 3 to provide a comparison with the other combinations 2-13.

According to one embodiment, the SUPL client **101** can also include a position-accuracy-improvement-determination-logic **180**B for determining the one or more position accuracy improvements to apply to the extracted pseudorange information based on one or more factors such as cost, quality of service, and one or more characteristics of the cellular device. For example, different costs are associated with different position accuracy improvements. More specifically, extracted pseudorange information, WAAS and Doppler information are typically free. There is a low cost typically associated with DGPS and real carrier phase information. There is typically a higher cost associated with PPP. Therefore, referring to Table 3, according to one embodiment, combinations 1, 2, and 3 are typically free, combinations 4-7 typically are low cost, and combinations 8-12 are typically higher cost.

Various cellular devices have different characteristics that make them capable of providing different types of position accuracy improvements. For example, one type of cellular device may be capable of providing WAAS but not be capable of providing Doppler information. In another example, some types of cellular devices may be capable of providing DGPS but not capable of providing PPP. In yet another example, different activities may require different levels of improvement. For example, some activities and/or people may be satisfied with 4-5 meters, others may be satisfied with 1.7 meters. Yet others may be satisfied with less than 1 meter, and still others may only be satisfied with 2 centimeters. Therefore, different users may request different levels of accuracy.

Table 4 depicts sources of the various position accuracy improvements, according to various embodiments.

TABLE 4

Sources of the Various Position Accuracy Improvements

Position Accuracy Improvement Name	Source
Pseudorange Information	extracted from GNSS chipset
WAAS	extracted from GNSS chipset or satellite broadcast via Internet or radio delivery
Real Carrier Phase Information	extracted from GNSS chipset
Doppler for reconstructing carrier phase information	extracted from GNSS chipset
Differential Global Positioning System (DGPS)	from a reference station delivered by dialing up, wired/wireless internet/intranet connection, or by receiving a broadcast

TABLE 4-continued

Sources of the Various Position Accuracy Improvements	
Position Accuracy Improvement Name	Source
	subcarrier modulation concatenated to an FM carrier frequency. DGPS can be obtained at least from Trimble ®
Real Time Kinematic (RTK)	from a reference station

The first column of Table 4 provides the name of the position accuracy improvement. The second column of Table 4 specifies the source for the corresponding position accuracy improvement.

According to various embodiments, a cellular device **100**, **200** can initially provide a position that is within 4-5 meters using, for example, unimproved extracted pseudorange information and the position can continually be improved, using various position accuracy improvements as described herein, as long as the antennae of the cellular device **100**, **200** is clear of obstructions to receive various position accuracy improvements.

The following describes various position accuracy improvements and related topics in more detail.

Global Navigation Satellite Systems

A Global Navigation Satellite System (GNSS) is a navigation system that makes use of a constellation of satellites orbiting the earth to provide signals to a receiver, such as GNSS receiver **107**, which estimates its position relative to the earth from those signals. Examples of such satellite systems are the NAVSTAR Global Positioning System (GPS) deployed and maintained by the United States, the GLObal NAvigation Satellite System (GLONASS) deployed by the Soviet Union and maintained by the Russian Federation, and the GALILEO system currently being deployed by the European Union (EU).

Each GPS satellite transmits continuously using two radio frequencies in the L-band, referred to as L**1** and L**2**, at respective frequencies of 1575.41 MHz and 1227.60 MHz. Two signals are transmitted on L**1**, one for civil users and the other for users authorized by the Unites States Department of Defense (DoD). One signal is transmitted on L**2**, intended only for DoD-authorized users. Each GPS signal has a carrier at the L**1** and L**2** frequencies, a pseudo-random number (PRN) code, and satellite navigation data.

Two different PRN codes are transmitted by each satellite: A coarse acquisition (C/A) code and a precision (P/Y) code which is encrypted for use by authorized users. A receiver, such as GNSS receiver **107**, designed for precision positioning contains multiple channels, each of which can track the signals on both L**1** and L**2** frequencies from a GPS satellite in view above the horizon at the receiver antenna, and from these computes the observables for that satellite comprising the L**1** pseudorange, possibly the L**2** pseudorange and the coherent L**1** and L**2** carrier phases. Coherent phase tracking implies that the carrier phases from two channels assigned to the same satellite and frequency will differ only by an integer number of cycles.

Each GLONASS satellite transmits continuously using two radio frequency bands in the L-band, also referred to as L**1** and L**2**. Each satellite transmits on one of multiple frequencies within the L**1** and L**2** bands respectively centered at frequencies of 1602.0 MHz and 1246.0 MHz. The code and carrier signal structure is similar to that of NAVSTAR. A

GNSS receiver designed for precision positioning contains multiple channels each of which can track the signals from both GPS and GLONASS satellites on their respective L**1** and L**2** frequencies, and generate pseudorange and carrier phase observables from these. Future generations of GNSS receivers will include the ability to track signals from all deployed GNSSs.

Differential Global Positioning System (DGPS)

Differential GPS (DGPS) utilizes a reference station which is located at a surveyed position to gather data and deduce corrections for the various error contributions which reduce the precision of determining a position fix. For example, as the GPS signals pass through the ionosphere and troposphere, propagation delays may occur. Other factors which may reduce the precision of determining a position fix may include satellite clock errors, GPS receiver clock errors, and satellite position errors (ephemerides). The reference station receives essentially the same GPS signals as cellular devices **100**, **200** which may also be operating in the area. However, instead of using the timing signals from the GPS satellites to calculate its position, it uses its known position to calculate timing. In other words, the reference station determines what the timing signals from the GPS satellites should be in order to calculate the position at which the reference station is known to be. The difference in timing can be expressed in terms of pseudorange lengths, in meters. The difference between the received GPS signals and what they optimally should be is used as an error correction factor for other GPS receivers in the area. Typically, the reference station broadcasts the error correction to, for example, a cellular device **100**, **200** which uses this data to determine its position more precisely. Alternatively, the error corrections may be stored for later retrieval and correction via post-processing techniques.

DGPS corrections cover errors caused by satellite clocks, ephemeris, and the atmosphere in the form of ionosphere errors and troposphere errors. The nearer a DGPS reference station is to the receiver **107** the more useful the DGPS corrections from that reference station will be.

The system is called DGPS when GPS is the only constellation used for Differential GNSS. DGPS provides an accuracy on the order of 1 meter or 1 sigma for users in a range that is approximately in a few tens of kilometers (kms) from the reference station and growing at the rate of 1 m per 150 km of separation. DGPS is one type of Differential GNSS (DGNSS) technique. There are other types of DGNSS techniques, such as RTK and Wide Area RTK (WARTK), that can be used by high-precision applications for navigation or surveying that can be based on using carrier phase measurements. It should be appreciated that other DGNSS which may utilize signals from other constellations besides the GPS constellation or from combinations of constellations. Embodiments described herein may be employed with other DGNSS techniques besides DGPS.

A variety of different techniques may be used to deliver differential corrections that are used for DGNSS techniques. In one example, DGNSS corrections are broadcast over an FM subcarrier. U.S. Pat. No. 5,477,228 by Tiwari et al. describes a system for delivering differential corrections via FM subcarrier broadcast method, the contents of which are incorporated herein by reference.

Real-Time Kinematic System

An improvement to DGPS methods is referred to as Real-time Kinematic (RTK). As in the DGPS method, the RTK method, utilizes a reference station located at determined or surveyed point. The reference station collects data from the same set of satellites in view by the cellular device **100**, **200** in the area. Measurements of GPS signal errors taken at the reference station (e.g., dual-frequency code and carrier phase signal errors) and broadcast to one or more cellular devices **100**, **200** working in the area. The one or more cellular devices **100**, **200** combine the reference station data with locally collected position measurements to estimate local carrier-phase ambiguities, thus allowing a more precise determination of the cellular device **100**, **200**'s position. The RTK method is different from DGPS methods in that the vector from a reference station to a cellular device **100**, **200** is determined (e.g., using the double differences method). In DGPS methods, reference stations are used to calculate the changes needed in each pseudorange for a given satellite in view of the reference station, and the cellular device **100**, **200**, to correct for the various error contributions. Thus, DGPS systems broadcast pseudorange correction numbers second-by-second for each satellite in view, or store the data for later retrieval as described above.

RTK allows surveyors to determine a true surveyed data point in real time, while taking the data. However, the range of useful corrections with a single reference station is typically limited to about 70 km because the variable in propagation delay (increase in apparent path length from satellite to a receiver of the cellular device **100**, **200**, or pseudo range) changes significantly for separation distances beyond 70 km. This is because the ionosphere is typically not homogeneous in its density of electrons, and because the electron density may change based on, for example, the sun's position and therefore time of day.

Thus for surveying or other positioning systems which must work over larger regions, the surveyor must either place additional base stations in the regions of interest, or move his base stations from place to place. This range limitation has led to the development of more complex enhancements that have superseded the normal RTK operations described above, and in some cases eliminated the need for a base station GPS receiver altogether. This enhancement is referred to as the "Network RTK" or "Virtual Reference Station" (VRS) system and method.

FIG. **4** depicts a flowchart **400** for determining an RTK position solution, according to one embodiment. At **410**, the method begins. The inputs to the method are reference station network or VRS corrections **412** and GNSS pseudorange plus carrier phase information from the cellular device **414**. At **420**, reference corrections and cellular device data are synchronized and corrections are applied to the GNSS data for atmospheric models and so on. The output of **420** is synchronized GNSS data **422**, which is received by operation **430**. At **430**, position, carrier phase ambiguities in floating point, and nuisance parameters are estimated. The output **432** of **430** is user position plus carrier phase ambiguities in floating point. Operation **440** receives the output **432** and produces improved user-position estimates using the integer-nature of carrier phase ambiguities. The output **442** of **440** is an RTK position solution, which can be used according to various embodiments. The method ends at **450**.

Network RTK

Network RTK typically uses three or more GPS reference stations to collect GPS data and extract information about the atmospheric and satellite ephemeris errors affecting signals within the network coverage region. Data from all the various reference stations is transmitted to a central processing facility, or control center for Network RTK. Suitable software at the control center processes the reference station data to infer how atmospheric and/or satellite ephemeris errors vary over the region covered by the network.

The control center computer processor then applies a process which interpolates the atmospheric and/or satellite ephemeris errors at any given point within the network coverage area and generates a pseudo range correction comprising the actual pseudo ranges that can be used to create a virtual reference station. The control center then performs a series of calculations and creates a set of correction models that provide the cellular device **100**, **200** with the means to estimate the ionospheric path delay from each satellite in view from the cellular device **100**, **200**, and to take account other error contributions for those same satellites at the current instant in time for the cellular device **100**, **200**'s location.

The cellular device **100**, **200** is configured to couple a data-capable cellular telephone to its internal signal processing system. The user operating the cellular device **100**, **200** determines that he needs to activate the VRS process and initiates a call to the control center to make a connection with the processing computer.

The cellular device **100**, **200** sends its approximate position, based on raw GPS data from the satellites in view without any corrections, to the control center. Typically, this approximate position is accurate to approximately 4-7 meters. The user then requests a set of "modeled observables" for the specific location of the cellular device **100**, **200**. The control center performs a series of calculations and creates a set of correction models that provide the cellular device **100**, **200** with the means to estimate the ionospheric path delay from each satellite in view from the cellular device **100**, **200**, and to take into account other error contributions for those same satellites at the current instant in time for the cellular device **100**, **200**'s location. In other words, the corrections for a specific cellular device **100**, **200** at a specific location are determined on command by the central processor at the control center and a corrected data stream is sent from the control center to the cellular device **100**, **200**. Alternatively, the control center may instead send atmospheric and ephemeris corrections to the cellular device **100**, **200** which then uses that information to determine its position more precisely.

These corrections are now sufficiently precise that the high performance position accuracy standard of 2-3 cm may be determined, in real time, for any arbitrary cellular device **100**, **200**'s position. Thus a GPS enabled cellular device **100**, **200**'s raw GPS data fix can be corrected to a degree that makes it behave as if it were a surveyed reference location; hence the terminology "virtual reference station."

An example of a network RTK system in accordance with embodiments of the present invention is described in U.S. Pat. No. 5,899,957, entitled "Carrier Phase Differential GPS Corrections Network," by Peter Loomis, assigned to the assignee of the present invention and incorporated as reference herein in its entirety.

The Virtual Reference Station method extends the allowable distance from any reference station to the cellular devices **100**, **200**. Reference stations may now be located hundreds of miles apart, and corrections can be generated for any point within an area surrounded by reference stations. However, there are many construction projects where cellular coverage is not available over the entire physical area under construction and survey.

Virtual Reference Stations

To achieve very accurate positioning (to several centimeters or less) of a terrestrial mobile platform of a cellular device

100, **200**, relative or differential positioning methods are commonly employed. These methods use a GNSS reference receiver located at a known position, in addition to the data from a GNSS receiver **107** on the mobile platform, to compute the estimated position of the mobile platform relative to the reference receiver.

The most accurate known method uses relative GNSS carrier phase interferometry between the GNSS cellular device **100**, **200**'s receiver and GNSS reference receiver antennas plus resolution of integer wavelength ambiguities in the differential phases to achieve centimeter-level positioning accuracies. These differential GNSS methods are predicated on the near exact correlation of several common errors in the cellular device **100**, **200** and reference observables. They include ionosphere and troposphere signal delay errors, satellite orbit and clock errors, and receiver clock errors.

When the baseline length between the mobile platform and the reference receiver does not exceed 10 kilometers, which is normally considered a short baseline condition, the ionosphere and troposphere signal delay errors in the observables from the cellular device **100**, **200** and reference receivers are almost exactly the same. These atmospheric delay errors therefore cancel in the cellular device **100**, **200**'s reference differential GNSS observables, and the carrier phase ambiguity resolution process required for achieving centimeter-level relative positioning accuracy is not perturbed by them. If the baseline length increases beyond 10 kilometers (considered a long baseline condition), these errors at the cellular device **100**, **200** and reference receiver antennas become increasingly different, so that their presence in the cellular device **100**, **200**'s-reference differential GNSS observables and their influence on the ambiguity resolution process increases. Ambiguity resolution on single cellular device **100**, **200**'s reference receiver baselines beyond 10 kilometers becomes increasingly unreliable. This attribute limits the precise resolution of a mobile platform with respect to a single reference receiver, and essentially makes it unusable on a mobile mapping platform that covers large distances as part of its mission, such as an aircraft.

A network GNSS method computes the estimated position of a cellular device **100**, **200**'s receiver using reference observables from three or more reference receivers that approximately surround the cellular device **100**, **200**'s receiver trajectory. This implies that the cellular device **100**, **200**'s receiver trajectory is mostly contained by a closed polygon whose vertices are the reference receiver antennas. The cellular device **100**, **200**'s receiver **107** can move a few kilometers outside this polygon without significant loss of positioning accuracy. A network GNSS algorithm calibrates the ionosphere and troposphere signal delays at each reference receiver position and then interpolates and possibly extrapolates these to the cellular device **100**, **200**'s position to achieve better signal delay cancellation on long baselines than could be had with a single reference receiver. Various methods of signal processing can be used, however they all yield essentially the same performance improvement on long baselines.

Kinematic ambiguity resolution (KAR) satellite navigation is a technique used in numerous applications requiring high position accuracy. KAR is based on the use of carrier phase measurements of satellite positioning system signals, where a single reference station provides the real-time corrections with high accuracy. KAR combines the L**1** and L**2** carrier phases from the cellular device **100**, **200** and reference receivers so as to establish a relative phase interferometry position of the cellular device **100**, **200**'s antenna with respect to the reference antenna. A coherent L**1** or L**2** carrier phase observable can be represented as a precise pseudorange scaled by the carrier wavelength and biased by an integer number of unknown cycles known as cycle ambiguities. Differential combinations of carrier phases from the cellular device **100**, **200** and reference receivers result in the cancellation of all common mode range errors except the integer ambiguities. An ambiguity resolution algorithm uses redundant carrier phase observables from the cellular device **100**, **200** and reference receivers, and the known reference antenna position, to estimate and thereby resolve these ambiguities.

Once the integer cycle ambiguities are known, the cellular device **100**, **200**'s receiver **107** can compute its antenna position with accuracies generally on the order of a few centimeters, provided that the cellular device **100**, **200** and reference antennas are not separated by more than 10 kilometers. This method of precise positioning performed in real-time is commonly referred to as real-time kinematic (RTK) positioning. The separation between a cellular device **100**, **200** and reference antennas shall be referred to as "cellular device reference separation."

The reason for the cellular device-reference separation constraint is that KAR positioning relies on near exact correlation of atmospheric signal delay errors between the cellular device **100**, **200** and reference receiver observables, so that they cancel in the cellular device **100**, **200**'s reference observables combinations (for example, differences between cellular device **100**, **200** and reference observables per satellite). The largest error in carrier-phase positioning solutions is introduced by the ionosphere, a layer of charged gases surrounding the earth. When the signals radiated from the satellites penetrate the ionosphere on their way to the ground-based receivers, they experience delays in their signal travel times and shifts in their carrier phases. A second significant source of error is the troposphere delay. When the signals radiated from the satellites penetrate the troposphere on their way to the ground-based receivers, they experience delays in their signal travel times that are dependent on the temperature, pressure and humidity of the atmosphere along the signal paths. Fast and reliable positioning requires good models of the spatio-temporal correlations of the ionosphere and troposphere to correct for these non-geometric influences.

When the cellular device **100**, **200** reference separation exceeds 10 kilometers, as maybe the case when the cellular device **100**, **200** has a GNSS receiver **107** that is a LEO satellite receiver, the atmospheric delay errors become decorrelated and do not cancel exactly. The residual errors can now interfere with the ambiguity resolution process and thereby make correct ambiguity resolution and precise positioning less reliable.

The cellular device **100**, **200**'s reference separation constraint has made KAR positioning with a single reference receiver unsuitable for certain mobile positioning applications where the mission of the mobile platform of the cellular device **100**, **200** will typically exceed this constraint. One solution is to set up multiple reference receivers along the mobile platform's path so that at least one reference receiver falls within a 10 km radius of the mobile platform's estimated position.

Network GNSS methods using multiple reference stations of known location allow correction terms to be extracted from the signal measurements. Those corrections can be interpolated to all locations within the network. Network KAR is a technique that can achieve centimeter-level positioning accuracy on large project areas using a network of reference GNSS receivers. This technique operated in real-time is commonly referred to as network RTK. The network KAR algorithm combines the pseudorange and carrier phase observables from the reference receivers as well as their known positions to compute calibrated spatial and temporal models of the ionosphere and troposphere signal delays over the project area. These calibrated models provide corrections to the observables from the cellular device **100**, **200**'s receiver, so that the cellular device **100**, **200**'s receiver **107** can perform reliable ambiguity resolution on combinations of carrier phase observables from the cellular device **100**, **200** and some or all reference receivers. The number of reference receivers required to instrument a large project area is significantly less than what would be required to compute reliable single baseline KAR solutions at any point in the project area. See, for example, U.S. Pat. No. 5,477,458, "Network for Carrier Phase Differential GPS Corrections," and U.S. Pat. No. 5,899,957, "Carrier Phase Differential GPS Corrections Network". See also Liwen Dai et al., "Comparison of Interpolation Algorithms in Network-Based GPS Techniques," Journal of the Institute of Navigation, Vol. 50, No. 4 (Winter 1003-1004) for a comparison of different network GNSS implementations and comparisons of their respective performances.

A virtual reference station (VRS) network method is a particular implementation of a network GNSS method that is characterized by the method by which it computes corrective data for the purpose of cellular device **100**, **200**'s position accuracy improvement. A VRS network method comprises a VRS corrections generator and a single-baseline differential GNSS position generator such as a GNSS receiver **107** with differential GNSS capability. The VRS corrections generator has as input data the pseudorange and carrier phase observables on two or more frequencies from N reference receivers, each tracking signals from M GNSS satellites. The VRS corrections generator outputs a single set of M pseudorange and carrier phase observables that appear to originate from a virtual reference receiver at a specified position (hereafter called the VRS position) within the boundaries of the network defined by a polygon (or projected polygon) having all or some of the N reference receivers as vertices. The dominant observables errors comprising a receiver clock error, satellite clock errors, ionosphere and troposphere signal delay errors and noise all appear to be consistent with the VRS position. The single-baseline differential GNSS position generator implements a single-baseline differential GNSS position algorithm, of which numerous examples have been described in the literature. B. Hofmann-Wellenhof et al., Global Positioning System: Theory and Practice, 5th Edition, 1001 (hereinafter "Hofmann-Wellenhof [1001]"), gives comprehensive descriptions of different methods of differential GNSS position computation, ranging in accuracies from one meter to a few centimeters. The single-baseline differential GNSS position algorithm typically computes differences between the cellular device **100**, **200** and reference receiver observables to cancel atmospheric delay errors and other common mode errors such as orbital and satellite clock errors. The VRS position is usually specified to be close to or the same as the roving receiver's estimated position so that the actual atmospheric errors in the cellular device **100**, **200** receiver **107**'s observables approximately cancel the estimated atmospheric errors in the VRS observables in the cellular device **100**, **200**'s reference observables differences.

The VRS corrections generator computes the synthetic observables at each sampling epoch (typically once per second) from the geometric ranges between the VRS position and the M satellite positions as computed using well-known algorithms such as those given in IS-GPS-200G interface specification tilted "Navstar GPS Space Segment/Navigation User Interfaces," and dated 5 Sep. 2012. It estimates the typical pseudorange and phase errors comprising receiver clock error, satellite clock errors, ionospheric and tropospheric signal delay errors and noise, applicable at the VRS position from the N sets of M observables generated by the reference receivers, and adds these to the synthetic observables.

A network RTK system operated in real time requires each GNSS reference receiver to transmit its observables to a network server computer that computes and transmits the corrections and other relevant data to the GNSS cellular device **100**, **200**'s receiver **107**. The GNSS reference receivers, plus hardware to assemble and broadcast observables, are typically designed for this purpose and are installed specifically for the purpose of implementing the network. Consequently, those receivers are called dedicated (network) reference receivers.

An example of a VRS network is designed and manufactured by Trimble Navigation Limited, of Sunnyvale, Calif. The VRS network as delivered by Trimble includes a number of dedicated reference stations, a VRS server, multiple server-reference receiver bi-directional communication channels, and multiple server-cellular-device-bi-directional data communication channels. Each server-cellular device bi-directional communication channel serves one cellular device **100**, **200**. The reference stations provide their observables to the VRS server via the server-reference receiver bi-directional communication channels. These channels can be implemented by a public network such as the Internet. The bi-directional server-cellular-device communication channels can be radio modems or cellular telephone links, depending on the location of the server with respect to the cellular device **100**, **200**.

The VRS server combines the observables from the dedicated reference receivers to compute a set of synthetic observables at the VRS position and broadcasts these plus the VRS position in a standard differential GNSS (DGNSS) message format, such as one of the RTCM (Radio Technical Commission for Maritime Services) formats, an RTCA (Radio Technical Commission for Aeronautics) format or a proprietary format such as the CMR (Compact Measurement Report) or CMR+ format which are messaging system communication formats employed by Trimble Navigation Limited. Descriptions for numerous of such formats are widely available. For example, RTCM Standard 10403.1 for DGNSS Services—Version 3, published Oct. 26, 2006 (and Amendment 2 to the same, published Aug. 31, 2007) is available from the Radio Technical Commission for Maritime Services, 1800 N. Kent St., Suite 1060, Arlington, Va. 22209. The synthetic observables are the observables that a reference receiver located at the VRS position would measure. The VRS position is selected to be close to the cellular device **100**, **200**'s estimated position so that the cellular device **100**, **200**'s VRS separation is less than a maximum separation considered acceptable for the application. Consequently, the cellular device **100**, **200** receiver **107** must periodically transmit its approximate position to the VRS server. The main reason for this particular implementation of a real-time network RTK system is compatibility with RTK survey GNSS receivers that are designed to operate with a single reference receiver.

Descriptions of the VRS technique are provided in U.S. Pat. No. 6,324,473 of (hereinafter "Eschenbach") (see particularly col. 7, line 21 et seq.) and U.S. Patent application publication no. 2005/0064878, of B. O'Meagher (hereinafter "O'Meagher"), which are assigned to Trimble Navigation Limited; and in H. Landau et al., Virtual Reference Stations versus Broadcast Solutions in Network RTK, GNSS 2003 Proceedings, Graz, Austria (2003); each of which is incorporated herein by reference.

The term "VRS", as used henceforth in this document, is used as shorthand to refer to any system or technique which has the characteristics and functionality of VRS described or referenced herein and is not necessarily limited to a system from Trimble Navigation Ltd. Hence, the term "VRS" is used in this document merely to facilitate description and is used without derogation to any trademark rights of Trimble Navigation Ltd. or any subsidiary thereof or other related entity.

Precise Positioning Point (PPP)

Descriptions of a Precise Point Positioning (PPP) technique are provided in U.S. Patent application publication 20110187590, of Leandro, which is assigned to Trimble Navigation Limited and is incorporated herein by reference. Trimble Navigation Limited has commercialized a version of PPP corrections which it calls RTX™. PPP corrections can be any collection of data that provides corrections from a satellite in space, clock errors, ionosphere or troposphere, or a combination thereof. According to one embodiment, PPP corrections can be used in instead of WAAS or RTX™.

The term Precise Point Positioning (PPP), as used henceforth in this document, is used as shorthand to refer to any system or technique which has the characteristics and functionality of PPP described or referenced herein and is not necessarily limited to a system from Trimble Navigation Ltd. Hence, the term "PPP" is used in this document merely to facilitate description and is used without derogation to any trademark rights of Trimble Navigation Ltd. or any subsidiary thereof or other related entity. Techniques for generating PPP corrections are well known in the art. In general, a PPP system utilizes a network (which may be global) of GNSS reference receivers tracking navigation satellites such as GPS and GLONASS satellites and feeding data back to a centralized location for processing. At the centralized location, the precise orbits and precise clocks of all of the tracked navigation satellites are generated and updated in real time. A correction stream is produced by the central location; the correction stream contains the orbit and clock information. This correction stream is broadcast or otherwise provided to GNSS receivers, such as a GNSS receiver **107**, in the field (conventionally by satellite service or cellular link) Corrections processors in the GNSS receivers utilize the corrections to produce centimeter level positions after a short convergence time (e.g., less than 30 minutes). A main difference between PPP and VRS is that PPP networks of reference receivers are typically global while VRS networks may be regional or localized with shorter spacing between the reference stations in a VRS network.

Wide Area Augmentation System (WAAS)

Wide Area Augmentation System (WAAS) corrections are corrections of satellite position and their behavior. WAAS was developed by the Federal Aviation Administration (FAA). WAAS includes a network of reference stations that are on the ground located in North America and Hawaii. The reference stations transmit their respective measurements to master stations which queue their respective received measurements. The master stations transmit WAAS corrections to geostationary WAAS satellites, which in turn broadcast the WAAS corrections back to earth where cellular devices **100**, **200** that include WAAS-enabled GPS receivers can receive the broadcasted WAAS corrections. According to one embodiment, the GNSS receiver **107** is a WAAS-enabled GPS receiver. The WAAS corrections can be used to improve the accuracy of the respective cellular devices **100**, **200'** positions, for example, by applying the WAAS corrections to extracted pseudoranges. WAAS operation and implementation is well known in the art.

Real Carrier Phase Information

According to one embodiment, a GNSS chipset **170** provides real carrier phase information (also referred to as "actual carrier phase information"). The cellular device **100**, **200** can extract real carrier phase information from the GNSS chipset **170** in a manner similar to extracting pseudorange information from the GNSS chipset **170**, where the extracted carrier phase information is for use elsewhere in the cellular device **100**, **200** outside of the GNSS chipset **170** as described herein, for example, with flowchart **600** of FIG. **6**.

FIG. **5**A is a flowchart **500**A of a method for performing a carrier phase smoothing operation using real carrier phase information, according to one embodiment. In various embodiments, carrier phase smoothing logic **152** may be implemented by either a range domain hatch filter, or a position domain hatch filter, or by any of other implementations known in the literature. The range domain hatch filter method is described in U.S. Pat. No. 5,471,217 by Hatch et al., entitled "Method and Apparatus for Smoothing Coded Measurements in a Global Positioning System Receiver," filed Feb. 1, 1993, incorporated by reference herein, and the Hatch paper entitled "The synergism of GPS code and carrier measurements," published in the Proceedings of the Third International Geodetic symposium on satellite Doppler Positioning, New Mexico, 1982: 1213-1232. See also p 45 of the Master's Thesis by Sudha Neelima Thipparthi entitled "Improving Positional Accuracy using Carrier Smoothing Techniques in Inexpensive GPS Receivers," MSEE thesis, New Mexico State University, Las Cruces, N. Mex., February 2004.

The filtering/processing described herein lies in the family of errors in pseudorange processing that affect code and carrier measurements in the same way. In various embodiments, the code phase pseudorange measurements are "disciplined" by subtracting out a more constant equivalent pseudorange-like distance measurement derived from the carrier phase. Next, a filtering on the net subtracted signal is performed which allows various embodiments to eliminate multipath induced errors in the raw, and corrected, pseudorange data. This method does not deal with ionospheric effects, according to one embodiment.

In operation **501**A of FIG. **5**A, extracted pseudorange information and carrier phases for a first epoch are collected. In one embodiment, these extracted pseudorange information and carrier phases are received at carrier phase smoothing logic **152** from the GNSS receiver **107**.

In operation **502**A of FIG. **5**A, pseudorange corrections are collected and applied to the first set of extracted pseudoranges collected in operation **501**A. In one embodiment, these corrections themselves may be smoothed at the reference receiver (e.g., at GPS/GNSS reference stations **220**) so that the delivered pseudorange corrections themselves are less noisy. Smoothing the pseudorange corrections derived at the GPS/GNSS reference stations **220** using the same carrier phase method of flowchart **500**A can vastly improve the quality of the delivered pseudorange corrections delivered to cellular device **100**, **200** for use by a position determination processor (e.g., GNSS receiver **107** or pseudorange information processing logic **150**). Such corrected pseudoranges that are also smoothed may be used by the cellular device **100**, **200** and fetched if available.

In operation **503**A of FIG. **5**A, delta carrier phase measurements for the same epoch are created using real carrier phase information. In accordance with various embodiments, this replicates creating a second distance measurement, similar to the reconstructed carrier phase information, based on integrated Doppler Shift.

In operation **504**A of FIG. **5**A, the delta carrier phase measurements are subtracted from the corrected extracted pseudoranges. In accordance with various embodiments, this provides a fairly constant signal for that epoch and is equivalent to the corrected extracted pseudorange at the start of the integration interval. In accordance with various embodiments, this is referred to as a "disciplining" step that smoothes out the corrected extracted pseudorange signal and therefore reduces the instant errors in the later-computed position fixes.

In operation **505**A of FIG. **5**A, the signal is filtered after the subtraction of operation **504**A to reduce noise. In accordance with one embodiment, this is performed by averaging the carrier phase "yardsticks" over a series of epochs.

In operation **506**A of FIG. **5**A, the delta carrier phase measurements from the real carrier phase processing operation is added back into the filtered signal of operation **505**A.

In operation **507**A of FIG. **5**A, the new filtered and corrected extracted pseudorange signal is processed, for example, at the pseudorange information processing logic **150**, to derive a position fix **172**B.

Reconstructing Carrier Phase Information Based on Doppler Shift

Carrier Phase Information can be reconstructed (referred to herein as "reconstructed carrier phase") based on Doppler Shift. Doppler Shift is the change in frequency of a periodic event (also known as a "wave") perceived by an observer that is moving relative to a source of the periodic event. For example, Doppler shift refers to the change in apparent received satellite signal frequency caused by the relative motion of the satellites as they either approach the cellular device **100**, **200** or recede from it. Thus any measurement of Doppler frequency change is similar to differentiating carrier phase. It is therefore possible to reconstruct the carrier phase by integrating the Doppler shift data. In an embodiment, the GNSS chipset **170** of GNSS receiver **107** may provide Doppler information it determines through other means. This Doppler frequency shift information or "Doppler" may be collected at each GPS timing epoch (e.g., one second) and integrated over a sequence of the one-second epochs, to produce a model of carrier phase. This Doppler-derived carrier phase model may be substituted for the real carrier phase data, and used in the same manner as shown in the flow chart for carrier phase smoothing of FIG. **5**A. Doppler Shift signal processing is well known in the art.

FIG. **5**B is a flowchart **500**B of a method for generating reconstructed carrier phase information (also referred to as a "Doppler-derived carrier phase model") based on Doppler Shift, according to one embodiment. In accordance with one embodiment, method of flowchart **500**B is implemented at GPS/GNSS reference stations and the modeled carrier phase is provided to cellular device **100**, **200** via one of the communication networks described above.

In operation **501**B of FIG. **5**B, Doppler information from a GNSS receiver **107** of a GNSS chipset **170** is received by pseudorange-carrier-phase-smoothing-logic **152**.

In operation **502**B of FIG. **5**B, a series of Doppler information is integrated. As described above, Doppler frequency shift information may be collected at each GPS timing epoch (e.g., one second) and stored for use in producing a model of carrier phase.

In operation **503**B of FIG. **5**B, a model of carrier phase is created based on integrated Doppler information. As discussed above with reference to operation **502**B, a series of Doppler information for a plurality of timing epochs is integrated. In one embodiment, this Doppler information is integrated over a sequence of the one-second epochs, to produce a model of carrier phase. The sequence may include 10-100 epochs, or seconds. The model of carrier phase smoothing is used as the reconstructed carrier phase information.

In operation **504**B of FIG. **5**B, the modeled carrier phase, which is also referred to as "reconstructed carrier phase information", is supplied to pseudorange-carrier-phase-smoothing-logic **152**. As described above, method of flowchart **500**B can be implemented at GPS/GNSS reference stations **220** and the reconstructed carrier phase information can then be broadcast to cellular device **100**, **200**.

Method of Extracting Pseudorange Information

FIG. **6** depicts a flowchart **600** of a method of extracting pseudorange information using a cellular device, according to one embodiment.

At **610**, the method begins.

At **620**, the cellular device **100**, **200** accesses the GNSS chipset **170** embedded within the cellular device **100**, **200** where the GNSS chipset **170** calculates pseudorange information for use by the GNSS chipset **170**. For example, the GNSS receiver **107** can perform GPS measurements to derive raw measurement data for a position of the cellular device **100**. The raw measurement data provides an instant location of the cellular device **100**. The GNSS chipset **170** calculates pseudorange information that is for use by the GNSS chipset **170**. According to one embodiment, the raw measurement data is the pseudorange information that will be extracted. Examples of pseudorange information are uncorrected pseudorange information, differential GNSS corrections, high precision GNSS satellite orbital data, GNSS satellite broadcast ephemeris data, and ionospheric projections.

A chipset accessor logic **141**, according to one embodiment, is configured for accessing the GNSS chipset **170**. According to one embodiment, the chipset accessor logic **141** is a part of an SUPL client **101**.

The pseudorange information can be obtained from the processor **172** of the GNSS receiver **107** using a command. The GNSS chipset **170** may be designed, for example, by the manufacturer of the GNSS chipset **170**, to provide requested information, such as pseudorange information, in response to receiving the command. The pseudorange information may be extracted from the GNSS chipset **170** using the command that the manufacturer has designed the GNSS chipset **170** with. For example, according to one embodiment, the GNSS chipset **170** is accessed using an operation that is a session started with a message that is an improved accuracy Secure User Platform Location (SUPL) start message or a high precision SUPL INIT message. According to one embodiment, the message is a custom command that is specific to the GNSS chipset **170** (also referred to as "a GNSS chipset custom command") and the improved accuracy SUPL client **101** can access to the raw measurements of the GNSS chipset **170**.

Examples of chipset manufacturers include Qualcomm, Texas Instruments, FastraX, Marvel, SIRF, Trimble, SONY, Furuno, Nemerix, Phillips, and XEMICS, to name a few.

At **630**, the cellular device **100**, **200** extracts the pseudorange information from the GNSS chipset **170** for use elsewhere in the cellular device **100**, **200** outside of the GNSS chipset **170**. For example, pseudorange information extractor logic **142** may be associated with a worker thread of the SUPL client **101**. The worker thread associated with the SUPL client **101** can monitor the raw measurements delivered by the GNSS chipset **170** into the GNSS chipset **170**'s memory buffers, cache the raw measurements and use the raw measurements to determine a position fix. The pseudorange information extractor logic **142** and the pseudorange information processing logic **150** can be associated with the worker thread. For example, the pseudorange information extractor logic **142** can cache the raw measurements and the pseudorange information processing logic **150** can determine the location.

According to one embodiment, the raw measurement data is the pseudorange information that is extracted. According to one embodiment, the raw measurement data is pseudorange information that is calculated by the GNSS chipset **170** and is only for use by the GNSS chipset **170**.

According to one embodiment, a determining position fix logic **170**B may perform a least squares solution **171**B on the extracted pseudorange information prior to transmitting the output to the pseudorange information bridger logic **143**. According to another embodiment, the extracted pseudorange information is improved using various embodiments described in FIGS. **7**A-**10** prior to performing a least squares solution **171**B, as will be described herein.

Methods of Improving Position Accuracy of Extracted Pseudorange Information

The extracted pseudorange information without further improvements can be used to provide an instant location, as described herein. The extracted pseudorange information can be improved by applying position accuracy improvements that include, but are not limited to, those depicted in Tables 2 and 3. The instant location or the improved location can be communicated to location manager logic **161**, as discussed herein, that displays the instant location or the improved location with respect to a map.

FIG. **7**A depicts a flowchart **700**A of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **710**A, the method begins.

At **720**A, the pseudorange-correction-logic **151** provides Wide Area Augmentation System (WAAS) corrected pseudoranges by applying WAAS corrections to the extracted pseudorange information. For example, the pseudorange-correction-logic **151** receives the extracted pseudorange information that was extracted from the GNSS chipset **170** at **630** of FIG. **6**. The cellular device **100**, **200** receives the WAAS corrections, as described herein, and provides the WAAS corrections to the pseudorange-correction-logic **151**. The pseudorange-correction-logic **151** provides Wide Area Augmentation System (WAAS) corrected pseudoranges by applying the received WAAS corrections to the extracted pseudorange information.

At **730**A the method ends.

FIG. **7**B depicts a flowchart **700**B of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **710**B, the method begins.

At **720**B, the pseudorange-carrier-phase-smoothing-logic **152** provides smoothed pseudorange information by performing pseudorange smoothing on the extracted pseudorange information based on carrier phase information. For example, if real carrier phase information is available, the cellular device **100**, **200** can extract it as discussed herein. Otherwise, the cellular device **100**, **200** can derive reconstructed carrier phase information as described herein and provide the reconstructed carrier phase information to the pseudorange-carrier-phase-smoothing-logic **152**. The pseudorange-carrier-phase-smoothing-logic **152** can receive the extracted pseudorange information that was extracted from the GNSS chipset **170** at **630** of FIG. **6**. The pseudorange-carrier-phase-smoothing-logic **152** can apply either the real carrier phase information or the real carrier phase information to the extracted pseudorange information to provide smoothed pseudorange information.

At **730**B, a position fix is determined based on the smoothed pseudorange information and WAAS pseudorange corrections. For example, the pseudorange-correction-logic **151** receives the smoothed pseudorange information and receives WAAS pseudorange corrections and determines a position fix based on the smoothed pseudorange information and the WAAS pseudorange corrections.

At **740**B, the method ends.

According to one embodiment, a determining position fix logic **170**B may perform a least squares solution **171**B on the output of flowchart **700**A and **700**B prior to transmitting the output to the pseudorange information bridger logic **143**.

FIG. **8**A depicts a flowchart **800**A of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **810**A, the method begins.

At **820**A, the pseudorange-correction-logic **151** provides Differential Global Positioning System (DGPS) corrected pseudoranges by applying DGPS corrections to the extracted pseudorange information.

For example, the pseudorange-correction-logic **151** receives the extracted pseudorange information that was extracted from the GNSS chipset **170** at **630** of FIG. **6**. The cellular device **100**, **200** receives the DGPS corrections as described herein and provides the DGPS corrections to the pseudorange-correction-logic **151**. The pseudorange-correction-logic **151** provides Differential Global Positioning System (DGPS) corrected pseudoranges by applying the received DGPS corrections to the extracted pseudorange information.

At **830**A, the pseudorange-correction-logic **151** provides WAAS-DGPS corrected pseudoranges by applying Wide Area Augmentation System (WAAS) to the DGPS corrected pseudoranges.

For example, the pseudorange-correction-logic **151** accesses the DGPS corrected pseudoranges determined at **820**A of FIG. **8**A. The cellular device **100**, **200** receives the WAAS corrections as described herein and provides the WAAS corrections to the pseudorange-correction-logic **151**. The pseudorange-correction-logic **151** provides WAAS-DGPS corrected pseudoranges by applying Wide Area Augmentation System (WAAS) to the DGPS corrected pseudoranges.

At **840**A, the method ends.

FIG. **8**B depicts a flowchart **800**B of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **810**B, the method begins.

At **820**B, a position determination decision is made as to whether to proceed to **822**B or **824**B. For example, at operation **820**B, the position accuracy improvement determination logic **180**B can determine whether to proceed to **822**B or **824**B as discussed herein.

At **830**B, DGPS corrected smoothed pseudoranges are provided by applying corrections to the smoothed pseudorange information. For example, the pseudorange-correction-logic **151** can provide DGPS corrected smoothed pseudoranges by applying DGPS corrections to the smoothed pseudoranges determined at either **822**B or **824**B.

At **840**B, WAAS-DGPS corrected smoothed pseudoranges are provided by applying WAAS to the DGPS corrected smoothed pseudoranges. For example, the pseudorange-correction-logic **151** can provide WAAS-DGPS corrected smoothed pseudoranges by applying WAAS corrections to the DGPS corrected smoothed pseudoranges.

At **850**B, the method ends.

According to one embodiment, a determining position fix logic **170**B may perform a least squares solution **171**B on the output of flowcharts **800**A or **800**B prior to transmitting the output to the pseudorange information bridger logic **143**.

FIG. **9**A depicts a flowchart **900**A of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **910**A, the method begins.

At **920**A, DGPS corrected pseudoranges are determined by applying DGPS pseudorange corrections to extracted pseudorange information. For example, the pseudorange-correction-logic **151** receives extracted pseudorange information from the pseudorange information extractor logic **142** and applies the DGPS pseudorange corrections to the extracted pseudorange information.

At **930**A, the pseudorange-correction-logic **151** can determine a position fix based on the DGPS corrected pseudoranges and PPP corrections.

At **940**A, the method ends.

FIG. **9**B depicts a flowchart **900**B of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **910**B, the method begins.

At **920**B, smoothed pseudorange information is provided by performing pseudorange smoothing on the extracted pseudorange information using carrier phase information. For example, the pseudorange-carrier-phase-smoothing-logic **152** provides smoothed pseudorange information by performing pseudorange smoothing on the extracted pseudorange information, which can be obtained as discussed herein, based on carrier phase information. If real carrier phase information is available, the cellular device **100**, **200** can extract the real carrier phase information, as discussed herein. Otherwise, the cellular device **100**, **200** can derive reconstructed carrier phase information, as described herein, and provide the reconstructed carrier phase information to the pseudorange-carrier-phase-smoothing-logic **152**.

At **930**B, DGPS corrected smoothed pseudoranges are provided by applying DGPS pseudorange corrections to the smoothed pseudorange information. For example, the pseudorange-correction-logic **151** can receive the smoothed pseudorange information from the pseudorange-carrier-phase-smoothing-logic **152**. The pseudorange-correction-logic **151** can determine the corrected smoothed pseudoranges by applying DGPS pseudorange corrections to the smoothed pseudorange information.

At **940**B, a position fix can be determined based on the DGPS corrected smoothed pseudoranges and PPP corrections. For example, the pseudorange-correction-logic **151** can determine a position fix based on the DGPS corrected smoothed pseudoranges and PPP corrections.

At **950**B, the method ends.

According to one embodiment, a determining position fix logic **170**B may perform a least squares solution **171**B on the output of flowcharts **900**A and **900**B prior to transmitting the output to the pseudorange information bridger logic **143**.

FIG. **10** depicts a flowchart **1000** of a method of improving the position accuracy using one or more position accuracy improvements, according to one embodiment.

At **1010**, the method begins.

At **1020**, the pseudorange-carrier-phase-smoothing-logic **152** smoothes the extracted pseudorange information based on carrier phase smoothing. For example, the pseudorange-carrier-phase-smoothing-logic **152** receives extracted pseudorange information from the pseudorange information extractor logic **142** and receives carrier phase information, which may be either real carrier phase information or reconstructed carrier phase information, as described herein. The pseudorange-carrier-phase-smoothing-logic **152** smoothes the extracted pseudorange information based on carrier phase smoothing.

At **1030**, the PPP logic **151**C provides a smoothed improved accuracy position fix by performing Precise Point Positioning (PPP) processing on the smoothed extracted pseudorange information. For example, the PPP logic **151**C receives the smoothed extracted pseudorange information provided by the pseudorange-carrier-phase-smoothing-logic **152** at **1020**. The PPP logic **151**C provides a smoothed improved accuracy position fix by performing Precise Point Positioning (PPP) processing on the smoothed extracted pseudorange information

At **1040**, the pseudorange-correction-logic **151** can optionally correct the smoothed improved accuracy position fix by applying Differential Global Positioning System (DGPS) corrections to the smoothed improved accuracy position fix. For example, pseudorange-correction-logic **151** receives the smoothed improved accuracy position fix provided by the PPP logic **151**C at **1030**. The pseudorange-correction-logic **151** receives DGPS corrections as described herein. The pseudorange-correction-logic **151** corrects the smoothed improved accuracy position fix by applying Differential Global Positioning System (DGPS) corrections to the smoothed improved accuracy position fix, thus, providing a corrected smoothed improved accuracy position fix. Operation **1040** is optional, according to one embodiment.

At **1050**, the method ends.

According to one embodiment, a determining position fix logic **170**B may perform a least squares solution **171**B on the output of flowchart **1000** prior to transmitting the output to the pseudorange information bridger logic **143**.

FIG. **11** depicts a flowchart **1100** of a method of accessing and processing extracted pseudorange information, according to one embodiment.

At **1110**, various types of information can be accessed. Examples of accessing are extracting **1112** information and receiving **1114** information. Unsmoothed uncorrected pseudorange information can be extracted at **1112**A, WAAS corrections can be extracted at **1112**B, SBAS corrections can be extracted at **1112**E, Doppler shift can be extracted at **1112**C, and carrier phase measurements can be extracted at **1112**D. "Accessing" and "obtaining" can be used interchangeably. Table 1 depicts types of information that can be extracted at operation **1112** from the GNSS chipset **170** and types of information that are received at operation **1114** instead of being extracted. However, various embodiments are not limited to the types of information that can be extracted or received depicted in Table 1.

The received or extracted information or a combination thereof, can be processed at **1120**.

What or whether to apply position accuracy improvements can be determined at **1160**, for example, by the position accuracy improvement determination logic **180**B. Examples of position accuracy improvements are real carrier phase information, reconstructed carrier phase information, WAAS, SBAS, DGPS, PPP, RTK, VRS and RTX™ corrections. The determination logic **180**B can determine whether one or more and in what order logics **152**A, **152**B, **151**A-**151**F are performed, according to one embodiment. Tables 2 and 3 are examples of carrier phase information or corrections or a combination thereof, that the position accuracy improvement determination logic **180**B may determine, as discussed herein.

The information can be smoothed at **1130**. Examples of smoothing **1130** are real carrier phase smoothing **1132** and reconstructed carrier phase smoothing **1134**.

Either unsmoothed information or smoothed information can be corrected at **1140**. For example, unsmoothed information from **1110** or smoothed information from **1130** can be corrected at **1140**. Examples of correcting are SBAS correcting **1140**G, WAAS correcting **1140**A, DGPS correcting **1140**B, PPP correcting **1140**C, RTK correcting **1140**D, VRS correcting **1140**E, and RTX correcting **1140**F. The smoothed information or unsmoothed information can be corrected using one or more of operations **1140**A-**1140**G. According to one embodiment, WAAS correcting **1140**A is an example of SBAS correcting **1140**G.

Unsmoothed information from **1110**, smoothed information from **1112**, corrected unsmoothed information from **1140** or corrected smoothed information from **1140** can be used to determine a position fix **172**B at **1150**, for example, by performing a least squares solution **171**B at **1152**. The output of flowchart **1100** is a position fix **172**B. Table 2 and Table 3 depict combinations of information that result in a position fix **172**B, according to various embodiments.

According to one embodiment, accessing **1110**, extracting **1112**, extracting pseudorange information **1112**A, extracting SBAS **1112**E, extracting WAAS **1112**B, extracting Doppler **1112**C, extracting carrier phase measurement **1112**D, receiving **1114**, smoothing **1130**, correcting **1140**, determining a position fix **1150**, and performing a least squares solution **1152** can be performed respectively by logic **110**B, **142**, **112**B-**5**, **112**B-**2**, **112**B-**3**, **112**B-**4**, **114**B, **150**, **152**, **151**, and **170**B. Real carrier phase smoothing **1132**, reconstructed carrier phase smoothing **1134**, correcting **1140**A-**1140**G can be performed respectively by logic **152**A, **152**B, **151**A-**151**E, **151**F, **151**G.

Any one or more of **1112**, **1112**A-**1112**E, **1132**, **1134**, **1140**A-**1140**G can be performed. Further, any one or more of **1112**, **1112**A-**1112**E, **1112**B, **1112**C, **1112**E, **1132**, **1134**, **1140**A-**1140**G can be performed in various orders. Various embodiments are not limited to just the combinations that are described herein.

According to one embodiment, a Global Navigation Satellite System (GNSS) chipset embedded within the cellular device is accessed at **620** (FIG. **6**) where the GNSS chipset calculates pseudorange information for use by the GNSS chipset. The pseudorange information is extracted at **640** (FIG. **6**), **112** (FIG. **11**) from the GNSS chipset for use elsewhere in the cellular device outside of the GNSS chipset. The accessing **620** and the extracting **640**, **1112**A can be performed by the cellular device **100**, **200** that includes hardware **180**.

The extracted pseudorange information can be smoothed at **1130**. The smoothing **1130** can be based on reconstructed carrier phase information or real carrier phase information. The smoothed pseudorange information can be corrected at **1140**. Examples of the types of corrected pseudoranges are Wide Area Augmentation System (WAAS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), and Real Time Kinematic (RTK). Pseudorange corrections can be accessed **1110**. The corrected pseudorange information can be derived, for example at **1140**, by applying the pseudorange corrections to the extracted pseudorange information.

FIGS. **4**-**11** depict flowcharts **400**-**1100**, according to one embodiment. Although specific operations are disclosed in flowcharts **400**-**1100**, such operations are exemplary. That is, embodiments of the present invention are well suited to performing various other operations or variations of the operations recited in flowcharts **400**-**1100**. It is appreciated that the operations in flowcharts **400**-**1100** may be performed in an order different than presented, and that not all of the operations in flowcharts **400**-**1100** may be performed.

The operations depicted in FIGS. **4**-**11** transform data or modify data to transform the state of a cellular device **100**, **200**. For example, by extracting pseudorange information from a GNSS chipset **170** for use elsewhere, the state of the cellular device **100**, **200** is transformed from a cellular device that is not capable of determining a position fix itself into a cellular device that is capable of determining a position fix itself. In another example, operations depicted in flowcharts **400**-**1100** transform the state of a cellular device **100**, **200** from not being capable of providing an improved accuracy position fix to be capable of providing an improved accuracy position fix.

The above illustration is only provided by way of example and not by way of limitation. There are other ways of performing the method described by flowcharts **400**-**1100**.

The operations depicted in FIGS. **4**-**11** can be implemented as computer readable instructions, hardware or firmware. According to one embodiment, hardware associated with a cellular device **100**, **200** can perform one or more of the operations depicted in FIGS. **4**-**11**.

Example GNSS Receiver

With reference now to FIG. **12**, a block diagram is shown of an embodiment of an example GNSS receiver which may be used in accordance with various embodiments described herein. In particular, FIG. **12** illustrates a block diagram of a GNSS receiver in the form of a general purpose GPS receiver **1230** capable of demodulation of the L**1** and/or L**2** signal(s) received from one or more GPS satellites. A more detailed discussion of the function of a receiver such as GPS receiver **1230** can be found in U.S. Pat. No. 5,621,416, by Gary R. Lennen, is titled "Optimized processing of signals for enhanced cross-correlation in a satellite positioning system receiver," and includes a GPS receiver very similar to GPS receiver **1230** of FIG. **12**.

In FIG. **12**, received L**1** and L**2** signals are generated by at least one GPS satellite. Each GPS satellite generates different signal L**1** and L**2** signals and they are processed by different digital channel processors **1252** which operate in the same way as one another. FIG. **12** shows GPS signals (L**1**=1575.42 MHz, L**2**=1227.60 MHz) entering GPS receiver **1230** through a dual frequency antenna **1232**. Antenna **1232** may be a magnetically mountable model commercially available from Trimble Navigation of Sunnyvale, Calif. Master oscillator **1248** provides the reference oscillator which drives all other clocks in the system. Frequency synthesizer **1238** takes the output of master oscillator **1248** and generates important clock and local oscillator frequencies used throughout the system. For example, in one embodiment frequency synthesizer **1238** generates several timing signals such as a 1st (local oscillator) signal LO**1** at 1400 MHz, a 2nd local oscillator signal LO2 at 175 MHz, an SCLK (sampling clock) signal at 25 MHz, and a MSEC (millisecond) signal used by the system as a measurement of local reference time.

A filter/LNA (Low Noise Amplifier) **1234** performs filtering and low noise amplification of both L**1** and L**2** signals. The noise figure of GPS receiver **1230** is dictated by the performance of the filter/LNA combination. The downconvertor **1236** mixes both L**1** and L**2** signals in frequency down to approximately 175 MHz and outputs the analogue L**1** and L**2** signals into an IF (intermediate frequency) processor **1250**. IF processor **1250** takes the analog L**1** and L**2** signals at approximately 175 MHz and converts them into digitally sampled L**1** and L**2** inphase (L**1** I and L**2** I) and quadrature signals (L**1** Q and L**2** Q) at carrier frequencies 420 KHz for L**1** and at 2.6 MHz for L**2** signals respectively.

At least one digital channel processor **1252** inputs the digitally sampled L**1** and L**2** inphase and quadrature signals. All digital channel processors **1252** are typically are identical by design and typically operate on identical input samples. Each digital channel processor **1252** is designed to digitally track the L**1** and L**2** signals produced by one satellite by tracking code and carrier signals and to from code and carrier phase measurements in conjunction with the GNSS microprocessor system **1254**. One digital channel processor **1252** is capable of tracking one satellite in both L**1** and L**2** channels. Microprocessor system **1254** is a general purpose computing device (such as computer system **1000** of FIG. **10**) which facilitates tracking and measurements processes, providing pseudorange and carrier phase measurements for a determining position fix logic **1258**. In one embodiment, microprocessor system **1254** provides signals to control the operation of one or more digital channel processors **1252**. According to one embodiment, the GNSS microprocessor system **1254** provides one or more of pseudorange information **1272**, Doppler Shift information **1274**, and real Carrier Phase Information **1276** to the determining position fix logic **1258**. One or more of pseudorange information **1272**, Doppler Shift information **1274**, and real Carrier Phase Information **1276** can also be obtained from storage **1260**. One or more of the signals **1272**, **1274**, **1276** can be conveyed to the cellular device's processor, such as processor **109** (FIG. **1**A) that is external to the GNSS chipset **170** (FIG. **1**A). Determining position fix logic **1258** performs the higher level function of combining measurements in such a way as to produce position, velocity and time information for the differential and surveying functions, for example, in the form of a position fix **1280**. Storage **1260** is coupled with determining position fix logic **1258** and microprocessor system **1254**. It is appreciated that storage **1260** may comprise a volatile or non-volatile storage such as a RAM or ROM, or some other computer readable memory device or media. In some embodiments, determining position fix logic **1258** performs one or more of the methods of position correction described herein.

In some embodiments, microprocessor **1254** and/or determining position fix logic **1258** receive additional inputs for use in receiving corrections information. According to one embodiment, an example of the corrections information is WAAS corrections. According to one embodiment, examples of corrections information are differential GPS corrections, RTK corrections, signals used by the previously referenced Enge-Talbot method, and wide area augmentation system (WAAS) corrections among others.

Although FIG. **12** depicts a GNSS receiver **1130** with navigation signals L**1**I, L**1**Q, L**2**I, L**2**Q, various embodiments are well suited different combinations of navigational signals. For example, according to one embodiment, the GNSS receiver **1130** may only have an L**1**I navigational signal. According to one embodiment, the GNSS receiver **1130** may only have L**1**I, L**1**Q and L**2**I.

Various embodiments are also well suited for future navigational signals. For example, various embodiments are well suited for the navigational signal L**2**C that is not currently generally available. However, there are plans to make it available for non-military receivers.

According to one embodiment, either or both of the accessing logic **110**B and the processing logic **150** reside at either or both of the storage **1260** and GNSS microprocessor system **1254**.

According to one embodiment, the GNSS receiver **1230** is an example of a GNSS receiver **107** (see e.g., FIG. **1**A and FIG. **1**D). According to one embodiment, the determining position fix logic **1258** is an example of determining position fix logic **170**B (FIG. **1**B). According to one embodiment, position fix **1280** is an example of a position fix **172**B (FIG. **1**B).

Kalman Filtering

FIG. **13** depicts an example Kalman filtering process **1300**, according to some embodiments. It should be appreciated that Kalman filtering is well known. As such, FIG. **13** and the associated discussion are utilized only to provide a high-level general description. Variations in the described procedures will occur during specific implementations of Kalman filtering. The extended Kalman filter and the unscented Kalman filter represent some of the variations to the basic method. Such variations are normal and expected. Generally speaking, Kalman filtering is a basic two-step predictor/corrector modeling process that is commonly used model dynamic systems. A dynamic system will often be described with a series of mathematical models. Models describing satellites in a Global Navigation Satellite System (GNSS) are one example of a dynamic system. Because the position of any satellite and/or the positions of all the satellites in a system constantly and dynamically change and the satellites output a signal that can be measured by a GNSS receiver, Kalman filtering can be used in determining positions of the satellites.

A basic Kalman filter implemented using Kalman filtering process **1300** typically has at least two major components **1310**: states **1311** and covariances **1312**. States **1311** represent variables that are used to describe a system being modeled, at a particular moment in time. Covariances **1312** are represented in a covariance matrix that describes uncertainty, or lack of confidence, of states **1311** with respect to each other at that same moment in time. Kalman filtering process **1300** also handles noise, or unpredictable variability, in the model. There are two principle types of noise, observation noise **1341** and process noise **1321**. A Kalman filter may handle additional noise types, in some embodiments. Process noise **1321** describes noise of the states **1311** as a function of time. Observation noise **1341** is noise that relates to the actual observation(s) **1340** (e.g., observed measurements) that are used as an input/update to Kalman filtering process **1300**.

A prediction phase **1320** is the first phase of Kalman filtering process **1300**. Prediction phase **1320** uses predictive models to propagate states **1311** to the time of an actual observation(s) **1340**. Prediction phase **1320** also uses process noise **1321** and predictive models to propagate the covariances **1312** to time of the actual observation(s) **1340** as well. The propagated states **1311** are used to make predicted observation(s) **1322** for the time of actual observation(s) **1340**.

A correction phase **1330** is the second phase in the Kalman filtering process **1300**. During correction phase **1330**, Kalman filtering process **1300** uses the difference between the predicted observation(s) **1322** and the actual observation(s) **1340** to create an observation measurement residual **1331**, which may commonly be called the "measurement residual." Observation noise **1341** can be noise in actual observation(s) **1340** and/or noise that occurs in the process of taking the actual observation(s) **1340**. A Kalman gain **1332** is calculated using both the covariances **1312** and the observation noise **1341**. The states **1311** are then updated using the Kalman Gain **1332** multiplied by the observation measurement residual **1331**. The covariances **1312** are also updated using a function related to the Kalman gain **1332**; for example, in one embodiment where Kalman gain is limited to a value between 0 and 1, this function may be 1 minus the Kalman gain. This updating is sometimes referred to as the "covariance update." In some embodiments, if no actual observation **1340** is available, Kalman filtering process **1300** can simply skip correction phase **1330** and update the states **1311** and covariances **1312** using only the information from prediction phase **1320**, and then begin again. Using the new definitions of the states **1311** and covariances **1312**, Kalman filtering process **1300** is ready to begin again and/or to be iteratively accomplished.

Computer Readable Storage Medium

Unless otherwise specified, any one or more of the embodiments described herein can be implemented using non-transitory computer readable storage medium and computer readable instructions which reside, for example, in computer-readable storage medium of a computer system or like device. The non-transitory computer readable storage medium can be any kind of physical memory that instructions can be stored on. Examples of the non-transitory computer readable storage medium include but are not limited to a disk, a compact disk (CD), a digital versatile device (DVD), read only memory (ROM), flash, and so on. As described above, certain processes and operations of various embodiments of the present invention are realized, in one embodiment, as a series of computer readable instructions (e.g., software program) that reside within non-transitory computer readable storage memory of a cellular device **100**, **200** (FIGS. **1A-2**) and are executed by a hardware processor of the cellular device **100**, **200**. When executed, the instructions cause a computer system to implement the functionality of various embodiments of the present invention. For example, the instructions can be executed by a central processing unit associated with the cellular device **100**, **200**. According to one embodiment, the non-transitory computer readable storage medium is tangible.

Unless otherwise specified, one or more of the various embodiments described herein can be implemented as hardware, such as circuitry, firmware, or computer readable instructions that are stored on non-transitory computer readable storage medium. The computer readable instructions of the various embodiments described herein can be executed by a hardware processor, such as central processing unit, to cause the cellular device **100**, **200** to implement the functionality of various embodiments. For example, according to one embodiment, the SUPL client **101** and the operations of the flowcharts **400-1100** depicted in FIGS. **4-11** are implemented with computer readable instructions that are stored on computer readable storage medium, which can be tangible or non-transitory or a combination thereof, and can be executed by a hardware processor **109** of a cellular device **100**, **200**.

CONCLUSION

Example embodiments of the subject matter are thus described. Although the subject matter has been described in a language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

Various embodiments have been described in various combinations and illustrations. However, any two or more embodiments or features may be combined. Further, any embodiment or feature may be used separately from any other embodiment or feature. Phrases, such as "an embodiment," "one embodiment," among others, used herein, are not necessarily referring to the same embodiment. Features, structures, or characteristics of any embodiment may be combined in any suitable manner with one or more other features, structures, or characteristics.

What is claimed is:

1. A method of extracting pseudorange information using a cellular device, the method comprising:

accessing a Global Navigation Satellite System (GNSS) chipset embedded within the cellular device, wherein the GNSS chipset calculates pseudorange information for use by the GNSS chipset;

extracting the pseudorange information from the GNSS chipset for use elsewhere in the cellular device outside of the GNSS chipset, wherein the accessing and the extracting are performed by the cellular device that includes hardware;

obtaining carrier phase information from the GNSS chipset, wherein the carrier phase information is real carrier phase information and wherein the obtaining of the carrier phase information further comprises extracting carrier phase measurements from the GNSS chipset, and deriving the real carrier phase information, external to the GNSS chipset, based on the extracted carrier phase measurements; and

storing the carrier phase information in memory located in the cellular device and outside of the GNSS chipset.

2. The method as recited by claim **1**, wherein the method further comprises:

providing smoothed pseudorange information by performing pseudorange smoothing on the extracted pseudorange information using the carrier phase information, wherein said pseudorange smoothing is performed external to the GNSS chipset.

3. The method as recited by claim **2**, wherein the method further comprises:

accessing the smoothed pseudorange information at pseudorange information processing logic resident in the cellular device; and

determining a position fix, external to the GNSS chipset, based on the smoothed pseudorange information.

4. The method as recited by claim **2**, wherein the method further comprises:

obtaining Wide Area Augmentation System (WAAS) pseudorange corrections; and

storing the WAAS pseudorange corrections in memory located in the cellular device and outside of the GNSS chipset.

5. The method as recited by claim **4**, wherein the method further comprises:

accessing the smoothed pseudorange information and the WAAS pseudorange corrections at pseudorange information processing logic resident in the cellular device; and determining a position fix, external to the GNSS chipset, based on the smoothed pseudorange information and the WAAS pseudorange corrections.

6. The method as recited by claim **2**, wherein the method further comprises:

obtaining Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source.

7. The method as recited by claim **6**, wherein the method further comprises:

providing DGPS corrected smoothed pseudoranges by applying the DGPS pseudorange corrections to the smoothed pseudorange information.

8. The method as recited by claim **7**, wherein the method further comprises:

obtaining Wide Area Augmentation System (WAAS) pseudorange corrections;

providing the DGPS corrected smoothed pseudoranges and the WAAS pseudorange corrections to the pseudorange information processing logic; and

determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges and the WAAS pseudorange corrections.

9. The method as recited by claim **7**, wherein the method further comprises:

accessing the DGPS corrected smoothed pseudoranges at the pseudorange information processing logic; and

determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges.

10. The method as recited by claim **6**, wherein the method further comprises:

obtaining Precise Point Positioning (PPP) corrections.

11. The method as recited by claim **10**, wherein the method further comprises:

if a distance between the cellular device and a nearest reference station is less than or equal to a distance threshold, providing corrected smoothed pseudoranges by applying the DGPS pseudorange corrections to the smoothed pseudorange information, wherein the applying of the DGPS pseudorange corrections is accomplished external to the GNSS chipset; and

if the distance is greater than the distance threshold, providing corrected smoothed pseudoranges by applying different pseudorange corrections to the smoothed pseudorange information, wherein the different pseudorange corrections is selected from a group consisting of SBAS corrections, WAAS corrections, RTX corrections and PPP corrections, wherein the applying of the different pseudorange corrections is accomplished external to the GNS chipset.

12. The method as recited by claim **11**, wherein the method further comprises:

if the corrected smoothed pseudoranges are DGPS corrected smoothed pseudoranges, then

accessing the DGPS corrected smoothed pseudoranges and the PPP corrections at pseudorange information processing logic, wherein the PPP corrections are orbit-clock errors; and

determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges and the PPP corrections.

13. The method as recited by claim **1**, wherein the method further comprises:

storing the extracted pseudorange information in memory located in the cellular device and outside of the GNSS chipset.

14. The method as recited by claim **13**, wherein the method further comprises:

accessing the extracted pseudorange information at pseudorange information processing logic resident in the cellular device; and

determining a position fix, external to the GNSS chipset, based on the extracted pseudorange information.

15. The method as recited by claim **14**, wherein the method further comprises:

obtaining Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source.

16. The method as recited by claim **15**, wherein the method further comprises:

accessing the extracted pseudorange information and the DGPS pseudorange corrections at the pseudorange information processing logic; and

determining a position fix, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information.

17. The method as recited by claim **14**, wherein the method further comprises:

obtaining Wide Area Augmentation System (WAAS) pseudorange corrections; and

storing the WAAS pseudorange corrections in memory located in the cellular device and outside of the GNSS chipset.

18. The method as recited by claim **17**, wherein the method further comprises:

obtaining Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source.

19. The method as recited by claim **18**, wherein the method further comprises:

accessing the extracted pseudorange information and the DGPS pseudorange corrections at pseudorange information processing logic resident at the cellular device;

determining DGPS corrected unsmoothed pseudoranges, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information;

accessing the WAAS pseudorange corrections at the pseudorange information processing logic; and

determining a position fix, external to the GNSS chipset, based on the DGPS corrected unsmoothed pseudoranges and the WAAS pseudorange corrections.

20. The method as recited by claim **13**, wherein the method further comprises:

obtaining Precise Point Positioning (PPP) corrections; and

storing the PPP corrections in memory located in the cellular device and outside of the GNSS chipset.

21. The method as recited by claim **20**, wherein the method further comprises:

obtaining Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source.

22. The method as recited by claim **21**, wherein the method further comprises:

accessing the extracted pseudorange information and the DGPS pseudorange corrections at pseudorange information processing logic resident at the cellular device;

determining DGPS corrected unsmoothed pseudoranges, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information;

accessing the DGPS corrected unsmoothed pseudoranges and the PPP corrections at pseudorange information processing logic; and

determining a position fix, external to the GNSS chipset, based on the DGPS corrected unsmoothed pseudoranges and the PPP corrections.

23. A non-transitory computer readable storage medium having computer readable instructions stored thereon for causing a computer system to perform a method of extracting pseudorange information using a cellular device, the method comprising:

accessing a Global Navigation Satellite System (GNSS) chipset embedded within the cellular device, wherein the GNSS chipset calculates pseudorange information for use by the GNSS chipset;

extracting the pseudorange information from the GNSS chipset for use elsewhere in the cellular device outside of the GNSS chipset, wherein the accessing and the extracting are performed by the cellular device;

obtaining carrier phase information from the GNSS chipset, wherein the carrier phase information is real carrier phase information and wherein the obtaining of the carrier phase information further comprises extracting carrier phase measurements from the GNSS chipset, and deriving the real carrier phase information, external to the GNSS chipset, based on the extracted carrier phase measurements; and

storing the carrier phase information in memory located in the cellular device and outside of the GNSS chipset.

24. The non-transitory computer readable storage medium as recited by claim **23**, wherein the method further comprises:

smoothing the extracted pseudorange information.

25. The non-transitory computer readable storage medium as recited by claim **24**, wherein the smoothing further comprises smoothing the extracted pseudorange information based on the carrier phase information.

26. The non-transitory computer readable storage medium as recited by claim **24**, wherein the method further comprises:

correcting the smoothed pseudorange information.

27. The non-transitory computer readable storage medium as by claim **26**, wherein the correcting of the smoothed pseudorange information further comprises providing corrected pseudoranges by correcting the smoothed pseudorange information, wherein the corrected pseudoranges are pseudoranges that were corrected based on one or more types of pseudorange corrections selected from a group consisting of satellite-based augmentation system (SBAS), Wide Area Augmentation System (WAAS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), Real Time Kinematic (RTK), and RTX.

28. The non-transitory computer readable storage medium as recited by claim **23**, wherein the method further comprises:

accessing, performed by the cellular device outside of the GNSS chipset, pseudorange corrections; and

deriving, performed by the cellular device outside of the GNSS chipset, the corrected pseudoranges by applying the pseudorange corrections to the extracted pseudorange information.

29. The non-transitory computer readable storage medium as recited by claim **28**, wherein the deriving the corrected pseudoranges further comprises deriving corrected pseudoranges that are pseudoranges that were corrected based on one or more types of pseudorange corrections selected from a group consisting of satellite-based augmentation system (SBAS), Wide Area Augmentation System (WAAS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), Real Time Kinematic (RTK) and RTX.

30. The non-transitory computer readable storage medium as recited by claim **23**, wherein the method further comprises:

determining whether to apply any improvements to the extracted pseudorange information; and

if the determination is to apply any improvements, determining one or more improvements to be applied to the extracted pseudorange information.

31. A system for extracting pseudorange information using a cellular device, the system comprising:

a chipset accessor for accessing a Global Navigation Satellite System (GNSS) chipset embedded within the cellular device, wherein the GNSS chipset calculates pseudorange information for use by the GNSS chipset;

a pseudorange information extractor for extracting the pseudorange information from the GNSS chipset for use elsewhere in the cellular device outside of the GNSS chipset, wherein the accessing and the extracting are performed by the cellular device that includes hardware;

carrier phase measurement extracting logic for extracting carrier phase measurements from the GNSS chipset;

real carrier phase logic for deriving real carrier phase information, external to the GNSS chipset, based on the extracted carrier phase measurements; and

memory for storing the real carrier phase information in the memory, wherein the memory is located in the cellular device and outside of the GNSS chipset.

32. The system as recited by claim **31**, wherein the system further comprises:

Doppler extracting logic for extracting Doppler shift data from the GNSS chipset;

reconstructed carrier phase logic for deriving reconstructed carrier phase information, external to the GNSS chipset, based on the extracted Doppler shift data; and

memory for storing the reconstructed carrier phase information in the memory, wherein the memory is located in the cellular device and outside of the GNSS chipset.

33. The system as recited by claim **31**, wherein the system further comprises:

smoothing logic for providing smoothed pseudorange information by performing pseudorange smoothing on the extracted pseudorange information using the carrier phase information, wherein said pseudorange smoothing is performed external to the GNSS chipset.

34. The system as recited by claim **33**, wherein the system further comprises:

pseudorange information processing logic for accessing the smoothed pseudorange information; and

determining position fix logic for determining a position fix, external to the GNSS chipset, based on the smoothed pseudorange information.

35. The system as recited by claim **33**, wherein the system further comprises:

accessing logic for accessing Wide Area Augmentation System (WAAS) pseudorange corrections, wherein the WAAS pseudorange corrections are for use elsewhere in the cellular device outside of the GNSS chipset;

memory for storing the WAAS pseudorange corrections in the memory, wherein the memory is located in the cellular device and outside of the GNSS chipset;

pseudorange information processing logic for accessing the smoothed pseudorange information and the WAAS pseudorange corrections, wherein the pseudorange information processing logic is resident in the cellular device; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the smoothed pseudorange information and the WAAS pseudorange corrections.

36. The system as recited by claim **33**, wherein the system further comprises:

receiving logic for receiving Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source; and

correcting logic for providing DGPS corrected smoothed pseudoranges by applying the DGPS pseudorange corrections to the smoothed pseudorange information.

37. The system as recited by claim **36**, wherein the system further comprises:

accessing logic for accessing Wide Area Augmentation System (WAAS) pseudorange corrections;

pseudorange information processing logic for receiving the DGPS corrected smoothed pseudoranges and the WAAS pseudorange corrections; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges and the WAAS pseudorange corrections.

38. The system as recited by claim **36**, wherein the system further comprises:

pseudorange information processing logic for accessing the DGPS corrected smoothed pseudoranges; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges.

39. The system as recited by claim **33**, wherein the system further comprises:

receiving logic for receiving Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source; and

pseudorange information processing logic for providing DGPS corrected smoothed pseudoranges by applying the DGPS pseudorange corrections to the smoothed pseudorange information, wherein applying is accomplished external to the GNSS chipset.

40. The system as recited by claim **39**, wherein the system further comprises:

the receiving logic for receiving Precise Point Positioning (PPP) corrections;

the pseudorange information processing logic for accessing the DGPS corrected smoothed pseudoranges and the PPP corrections; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the DGPS corrected smoothed pseudoranges and the PPP corrections.

41. The system as recited by claim **31**, wherein the system further comprises:

memory for storing the extracted pseudorange information in the memory, wherein the memory is located in the cellular device and outside of the GNSS chipset;

pseudorange information processing logic for accessing the extracted pseudorange information, wherein the pseudorange information processing logic is resident in the cellular device; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the extracted pseudorange information.

42. The system as recited by claim **41**, wherein the system further comprises:

receiving logic for receiving Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source;

the pseudorange information processing logic for accessing the extracted pseudorange information and the DGPS pseudorange corrections; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information.

43. The system as recited by claim **41**, wherein the system further comprises:

accessing logic for accessing Wide Area Augmentation System (WAAS) pseudorange corrections; and

the memory for storing the WAAS pseudorange corrections in the memory, wherein the memory is located in the cellular device and outside of the GNSS chipset.

44. The system as recited by claim **43**, wherein the system further comprises:

receiving logic for receiving Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source;

the pseudorange information processing logic for accessing the extracted pseudorange information and the DGPS pseudorange corrections, wherein the pseudorange information processing logic is resident at the cellular device;

the pseudorange information processing logic for determining DGPS corrected unsmoothed pseudoranges, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information;

the pseudorange information processing logic for accessing the WAAS pseudorange corrections; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the DGPS corrected unsmoothed pseudoranges and the WAAS pseudorange corrections.

45. The system as recited by claim **31**, wherein the system further comprises:

receiving logic for receiving Precise Point Positioning (PPP) corrections;

the receiving logic for receiving Differential Global Positioning System (DGPS) pseudorange corrections from a local DGPS reference source;

pseudorange information processing logic for accessing the extracted pseudorange information and the DGPS pseudorange corrections, wherein the pseudorange information processing logic is resident at the cellular device;

the pseudorange information processing logic for determining DGPS corrected unsmoothed pseudoranges, external to the GNSS chipset, by applying the DGPS pseudorange corrections to the extracted pseudorange information;

the pseudorange information processing logic for accessing the DGPS corrected unsmoothed pseudoranges and the PPP corrections; and

the pseudorange information processing logic for determining a position fix, external to the GNSS chipset, based on the DGPS corrected unsmoothed pseudoranges and the PPP corrections.

46. The system as recited by claim **31**, wherein the system further comprises:

smoothing logic for smoothing the extracted pseudorange information, wherein the smoothing logic is external to the GNSS chipset.

47. The system as recited by claim **46**, wherein the smoothing logic smooths the extracted pseudorange information based on the real carrier phase information.

48. The system as recited by claim **46**, wherein the system further comprises:

Doppler extracting logic for extracting Doppler shift data from the GNSS chipset;

reconstructed carrier phase logic for deriving reconstructed carrier phase information based on the extracted Doppler shift data; and

the reconstructed carrier phase logic for smoothing the extracted pseudorange information based on the reconstructed carrier phase information, wherein the Doppler extracting logic and the reconstructed carrier phase logic are external to the GNSS chipset.

49. The system as recited by claim **46**, wherein the system further comprises:

correcting logic for correcting the smoothed pseudorange information, wherein the correcting logic is external to the GNSS chipset.

50. The system as recited by claim **49**, wherein the corrected pseudoranges are pseudoranges that were corrected based on one or more types of pseudorange corrections selected from a group consisting of Wide Area Augmentation System (WAAS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), Real Time Kinematic (RTK), and RTX.

51. The system as recited by claim **31**, wherein the system further comprises:

accessing logic for accessing pseudorange corrections; and

pseudorange information processing logic for deriving the corrected pseudoranges by applying the pseudorange corrections to the extracted pseudorange information, wherein the accessing logic and the pseudorange information processing logic are external to the GNSS chipset.

52. The system as recited by claim **51**, wherein the corrected pseudoranges are pseudoranges that were corrected based on one or more types of pseudorange corrections selected from a group consisting of Wide Area Augmentation System (WAAS), Differential Global Positioning System (DGPS), Precise Point Positioning (PPP), Real Time Kinematic (RTK) and RTX.

53. The system as recited by claim **31**, wherein the system further comprises:

position accuracy improvement determination logic for determining whether to apply any improvements to the extracted pseudorange information, wherein the position accuracy improvement determination logic is external to the GNSS chipset; and

the position accuracy improvement determination logic for determining one or more improvements to be applied to the extracted pseudorange information, if the determination is that any improvements will be applied.

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